ASSESSMENT OF WATER BALANCES USING SWAT MODEL AND AGRICULTURAL WATER DEMAND ANALYSIS OF GIDABO RIVER CATCHMENT, RIFT VALLEY BASIN, ETHIOPIA.

MSc. THESIS

CHALA TADESSE

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

NOVEMBER, 18/2020

ASSESSMENT OF WATER BALANCE USING SWAT MODEL AND AGRICULTURAL WATER DEMAND ANALYSIS OF GIDABO RIVER CATCHMENT, ETHIOPIAN RIFT VALLEY BASIN

CHALA TADESSE

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCE
ENGINEERING AND MANAGEMENT,
HAWASSA SCHOOL OF BIOSYSTEM AND ENVIRONMENTAL ENGINEERING,
SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSITY
HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE
DEGREE OF

MASTERS OF SCIENCE IN WATER RESOURCE ENGINEERING AND MANAGEMENT

NOVEMBER, 2020

SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSITY

APPROVAL SHEET

ADVISORS APPROVAL SHEET

As Thesis research advisor, we hereby certify that we have read and evaluated this thesis prepared under our guidance by CHALA TADESSE entitled

"*Assessment of Water Balance Using Swat Model and Agricultural Water Demand Analysis of Gidabo River Catchment, Rift Valley Basin, Ethiopian*"

We recommend that it be submitted as fulfilment of the thesis requirement.

Approved by:

______________________	_________________	________________
Major Advisor	Signature	Date
______________________	__________________	________________
Co-advisor	Signature	Date

EXAMINERS' APPROVAL SHEET

As member of the Board of Examiners of the final open defence by Chala Tadesse, have read and evaluated his thesis entitled ***"Assessment of Water Balance Using Swat Model and Agricultural Water Demand Analysis of Gidabo River Catchment, Rift Valley Basin, Ethiopian"*** and examined the candidate. Therefore, I certify that the thesis is accepted in partial fulfilment of the requirement for the Degree of Master of Science in Water Resources Engineering and Management.

Major Advisor	Signature	Date
Internal Examiner	Signature	Date
Dr. Teshome Seyoum		14.03.2020
External Examiner	Signature	Date
SGS	Signature	Date

DEDICATION

This work is dedicated to my beloved Mother, Zerfe Jifar and my father Tadesse Bari, and my elder brother Birhanu Tadesse.

Mom and dad, you are not only my family. But also you are my teachers and the reason for being who I am and now I am here because of you dad.

DECLARATION

I, ***Chala Tadesse Bari***, declare that the thesis which I hereby submit for the "***Degree Of Master Of Science In Water Resource Engineering and Management at The University Of Hawassa"*** is my own work and has not previously been submitted and will not be submitted by me for a degree at this or any other institution. To the best of my knowledge and belief, except as acknowledged in the text, the thesis does not contain any written work presented by other persons whether pictures, graphs or data or any other. I also declare that I have complied with the rules, requirements, procedures, and policy of the university.

Student signature: ______________________

Date: Nov, 2020.

ACKNOWLEDGEMENT

Above all, I would like to thank the almighty God for giving me the strength and wisdom to reach this point in my life.

I would like to express my sincere gratitude to my employer Dilla University for providing me this chance. Thanks, DU, you made my dream come true.

I would like to express my sincere gratitude to my Advisor, Dr. Mulugeta Dadi for giving me valuable guidance, constructive comments, and support throughout my research. I am also indebted to my co-Advisor, Dr. Kannan N., for early feedback on the written documents. I am very grateful to all my teachers who taught me from grass root to this level.

I will also like to thank the Ethiopian Ministry of Water Resources, Irrigation and Energy (MoWIE), National Meteorological Services Agency (NMSA), International Water Management Institute (IWMI) and Rift Valley office for the data and keen assistance they gave me during data collection.

Thanks to God, I have a lot of exciting friends whom I met in my walk of life. Letters and words limit me to list your names. You all were great. I learned a lot from you. Those of you I met you at Hawassa University, thank you for those wonderful days we spent together and for the ideas and views we shared.

At last but not least, I would like to extend my deepest gratitude to my family, without your encouragement and care this would not be happened. Thanks to all of you.

LIST OF ABBREVIATION AND ACRONYMS

ArcSWAT	SWAT Integrated with ArcGIS
ARS	USDA Agricultural Research Service
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CN	Curve Number
DEM	Digital Elevation Model
ERSDAC	Earth Remote Sensing Data Analysis Center
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FAST	Fourier Amplitude Sensitivity Test
GDEM	Global Digital Elevation Model
GIS	Geographic Information System
HRU	Hydrologic Response Unit
ISRIC	International Soil Reference and Information Center
LH	Latine Hypercube
LULC	Land Use / Land Cover
m.a.s.l	mean above sea level
MoWE	Ministry of Water and Energy
NASA	National Aeronautics and Space Administration
NMSA	National Meteorological Service Agency
ENS	Nash-Sutcliffe Efficiency
OAT	One factor At a Time
Parasols	Parameter Solutions
PET	Potential Evapotranspiration
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
UNESCO	United Nation Educational Scientific and Cultural Organization
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WXGEN	Statistical weather generators file for SWAT

Contents

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

To use water resources sustainably, it is important to understand the quantity of water resource spatially and temporally. The work presented here attempts to model water balance of one of Gidabo sub-watershed of Ethiopian Rift Valley Basin using the Soil and Water Assessment Tool (SWAT. Statistical model performance measures, the coefficient of determination (R^2*) and Nash-Sutcliffe Efficiency (NSE) were used to evaluate the correlation between the observed and simulated monthly stream flow. The result shows an acceptable performance of SWAT model in simulating the watershed hydrology as evidenced by the NSE value of 0.79 and* R^2 *value of 0.80 at calibration (using data from1990-2009) and NSE = 0.71 and* R^2*=0.82 at validation (using data from2010-2014). In terms of water balance components, the long-term annual precipitation is found to be in the magnitude of 1435.58 mm; whereas the surface runoff; total water yield; and actual evapotranspiration, are estimated as 62.20; 1189.73, and 228.40 mm respectively. In order to link the water balance estimation with the local agricultural water demand, wheat and potato are selected for they are common crops for irrigation in the watershed. While taking the month of March, which is the month of maximum agricultural water demand (11.6* m^3/s*), the watershed is found to be water-surplus as indicated by the water availability of the critical month (12.22* m^3/s*) to be higher than the demand. This research implies that the use of models in supporting decisions related to* water resources development and management *is paramount important to understand how the system functions.*

KEYWORDS: Agricultural water requirements; Gidabo watershed; SWAT model; Water balance

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Understandings on hydrological processes to develop suitable models for a watershed are the most important aspect in water resource development and management programs. Water resource development is the basic and crucial infrastructure for a nation's sustainable development (Shawul, 2013). Major hydrological processes can be quantified with the help of water balance equations. The component of water balance of a basin is influenced by climate, and the geophysical characteristics of the watershed such as topography, land use and soil. Consideration of the relationship between these physical parameters and hydrological components is very essential for any water resource development related work (Sathian and Symala, 2009).

The modeling of runoff, soil erosion and sediment yield are essential for sustainable watershed development. Furthermore, reliable estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas is tedious and time consuming by conventional methods (Shawul, 2013). So it is desirable that some suitable methods and techniques are used for quantifying the hydrological parameters from all parts of the watersheds. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices a hydrological cycle is a complex system. As a result, use of mathematical models and geospatial analyses tools for studying hydrological processes and hydrological responses to land use and climatic changes is the current trend (Sanjayet al.,2010).

To utilize water in a sustainable manner, it is necessary to understand the quantity and quality in space and time through studies and researches (McCornick et al., 2003). Major hydrological processes can be quantified with the help of water balance equations. The component of water balance of a basin is influenced by climate, and the geophysical characteristics of the watershed such as topography, land use and soil. Consideration of the relationship between these physical parameters and hydrological components is very essential for any water resource development related work (Sathian and Symala, 2009). Since the hydrologic processes are very complex, their proper comprehension is essential and therefore, watershed based hydrological models are widely used.

To quantify the variability of hydrologic fluxes and flow of matter, a distributed watershed model with a high resolution of space and time is necessary. Human health and welfare, food security and industrial development are dependent on adequate supplies of suitable quality water. Conversely, too much water results in socioeconomic damages and loss of life due to flooding. The liveliness of natural ecological systems is dependent on mankind's stewardship of water resources. Proper utilization of these resources necessitates assessment and management of the quantity and quality of the water resources both spatially and temporally (Dilnesaw, 2006).

Land use practices such as deforestation, over grazing and agriculture affect ecosystem structure and well-functioning of regional climate. Negative pressures on natural resources in the area are rapidly growing. Rural communities are seeking to meet their livelihood needs by expanding exploitation of local natural resources.

Agricultural land is expanding rapidly, grazing areas are heavily degraded necessitating the search for new pasture, forest areas are being cut and cleared, and water systems disrupted. Unplanned and unrestricted settlement is a significant and mounting problem. Existing settlements are growing, and new settlements are appearing in previously unsettled and environmentally sensitive areas (Farm-Africa SOS Sahel Ethiopia, 2007).Water is a basic necessity for sustaining life and development of society. With the increasing population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (GWP, 2000).

Increase in water demand has reduced water availability during dry seasons and has as well increased water conflicts in the watersheds. Unless properly managed, increasing demand of the scarce water resources by different sectors will strongly affect all users and the environment (Hellström et al., 2000).

1.2 Problem statement

Increased agricultural water demand in the Gidabo watershed has resulted in increased surface water abstractions and is contributing to the imbalance between water demand and supply, during the low river flow. Growth in population, increased economic activities and improved standard of living has led to increased demand and competition for freshwater resources in Gidabo watershed.

Gidabo watershed is one of the watersheds draining in to the sub basin of Lake Abaya - Chamo, and this watershed is under great pressure because of growing population and increasing demand of water mainly for irrigation, which is not practiced well now a days in the catchment, and also a great demand of water for domestic and livestock consumption purposes. In addition, the growing uncertainty of surface water availability and increasing levels of water pollution and water diversions threaten to disrupt social and economic development in the area as well as the health of the ecosystem. Because of the importance of the Abbay River, many studies had been studied in the past though; there was no much specific study for the development of Gidabo watershed exclusively. This study was initiated to assess the surface water availability and agricultural demand situation in Gidabo river basin.

1.3 Objectives of the study

General:

The general objective of this research is to estimate water balance components of Gidabo watershed for the purpose of agricultural water demand.

Specific Objectives:

- To estimate the monthly and annual runoff yield and the water balance components of Gidabo river watershed.
- To assess current situation of Gidabo river watershed in terms of water availability and demand (Agricultural demand).

1.4 Research Questions

1) How to estimate monthly and annual runoff yield, and what are the water balance components of the study area?
2) What are the major components of the water balance controlling the hydrological behaviour of the watershed at large?
3) What are the current situation of Gidabo watershed in terms of water availability, agricultural demand and water resource planning?
4) How to calculate, identify and assess existing water demands of the proposed study area?

1.5 The scope of study

Extreme hydrological events and characteristics of River basins are influenced by different factors such as land use/cover, water use and climatic change. Therefore; this study limited to estimate water balance components and agricultural water demands in Gidabo river watershed by considering physical land characteristics (LULC), surface water potential and slope by using SWAT, SWAT- CUP and CROPWAT8.0 Model.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Factors Affecting Runoff

Apart from rainfall characteristic, there are a number of site specific factors which have a direct bearing on the occurrence and volume of runoff. The major factors are reviewed below.

2.1.1 Soil type

Soil functions essentially as medium that provides a large number of passageways for water. Water flow in soil depends on the size and permanency of the pores. The size of the conduits depends on the size of the soil texture, the degree of aggregation and the arrangements of particles and aggregates (Silveira et al., 2000). The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have smaller infiltration capacities. The infiltration capacity depends further more on the moisture content prevailing in a soil at the onset of a rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated (Finkel and Sergerros, 1995).

2.1.2 Vegetation

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. More significant is the effect the vegetation has on the infiltration capacity of the soil. Dense vegetation shields the soil from the raindrop impact and reduces the crusting effect as described earlier. In addition, the root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving more time to infiltrate and to evaporate (Finkel and Sergerros, 1995).

2.1.3 Slope and catchment characteristics

The volume and peak rate of runoff increases with catchment area. However, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. In the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet (Carey et al., 2004).

The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e., the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency. Investigation on experimental plots has shown that steep slope plots yield more runoff than those with gentle slopes (Ben Asher, 1988).

2.2 Effect of Land Use on Stream flow Regimes

2.2.1 Effect on mean flow

According to Seibert and McDonnell (2010), the effect of land use or land cover change on stream runoff dynamics is not fully understood. In many parts of the world, forest management is the major land cover change agent. While the paired catchment approach has been the primary methodology used to quantify such effects, it is only possible for small headwater catchments where there is uniformity in precipitation inputs and catchment characteristics between the treatment and control catchments.

Afforestation and deforestation are two of the most important land use changes influencing the hydrological response of catchments. Catchment experiments worldwide have demonstrated that substantially altering the type and extent of vegetative cover on a catchments can significantly affect the interception and evapotranspiration (ET) processes, consequently cause a change in the runoff volume. Generally, land use changes that reduce ET increase annual runoff from catchments, whereas land use changes that increase ET decrease annual runoff. Coniferous forest, deciduous hardwood, brush and grass cover (in that order) have been found to have a decreasing influence on annual runoff of the source areas in which the land covers are manipulated (Brooks et al., 1997). Brooks et al. (1997) explained that the degree of change in annual runoff from catchments depends on the intensity and extent of land development.

The generalized relationship based on catchments experiments worldwide is that a 10% reduction in coniferous forest (deciduous forest, shrub), being converted to grassland, causes an average increase of 40 mm (25 mm for deciduous forest, 10 mm for shrub) in annual runoff.

2.2.2 Effects on flood and low flows

Land use activities may affect storm flow response and in turn flood peaks through changes in vegetation cover, soil infiltration capacity, conveyance system, increased erosion and sedimentation (Brooks et al., 1997). The potential impacts of land use changes on surface and near surface hydrological processes (fluxes or storages) under "normal" conditions in humid temperature zones.

Forests and forest soils are popularly thought to influence the timing of stream flow by storing water during wet periods and releasing water during dry periods because of their high infiltration and soil moisture storage capacities, and hence reduce flood peaks. Conversely, deforestation is generally accepted to be a cause of increased flooding downstream (Bronstert et al., 2002)

2.3 Description of SWAT Model

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch et al., 2005). In recent years, SWAT model developed by Arnold et al. (1998), has gained international acceptance as a robust interdisciplinary watershed modeling. SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman et al., 2005). The review of SWAT model applicability to Ethiopian situations (Dilnesaw, 2006; Setegn, 2010) at relatively larger watersheds and (Ashenafi, 2009; Biniam, 2009; Eyob, 2010) indicated that the model is capable of simulating hydrological processes with reasonable accuracy and can be applied to large gauged watershed.

SWAT model can be a potential monitoring tool for watersheds in mountainous catchments of the tropical regions (Birhanu et al., 2007). SWAT is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in gauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-basins, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-basin area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-basins that are characterized by dominant land use, soil type, and management (Gassman et al., 2007).

2.3.1 Components of SWAT model

2.3.1.1 Hydrological components of SWAT model

The Simulation of the hydrology of a watershed is separated into two divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet (Neitsch et al., 2005). In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation:

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

Brief description of some of the key model components are provided in this study. More detailed descriptions of the different model components are listed in SWAT user’s manual (Neitsch et al., 2005). Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter.

When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will start. Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911; as cited in Neitsch et al., 2005). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. SCS defines three antecedent moisture conditions: I-dry (wilting point), II-average moisture and III-wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions.

SWAT calculates the peak runoff rate with a modified rational method. There are many methods that are developed to estimate potential evapotranspiration (PET). Three methods are incorporated into SWAT: the Penman-Monteith method (Monteith, 1965), the Priestley Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves et al., 1985) and the model will also read in daily PET values if the user prefers to apply a different PET methods.

Groundwater balance in SWAT model is calculated by assuming two layers of aquifers. SWAT partitions groundwater into a shallow unconfined aquifer and a deep confined aquifer and it simulates two aquifers in each sub-basin. The shallow aquifer is an unconfined aquifer that contributes to flow in the main channel or reach of the sub-basin. The deep aquifer is a confined aquifer. Water that enters the deep aquifer is assumed to contribute to stream flow somewhere outside of the watershed (Arnold et al., 1993).

2.3.1.2 The routing face of the hydrological cycle

Open channel flow is defined as channel flow with a free surface, such as flow in a river or partially full pipe. SWAT uses Manning’s equation to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. The details of the water routing methods and the descriptions of the different model components can be found in Neitsch et al. (2005).

2.4 Base flow Separation

Base flow separation techniques use the time-series record of stream flow to derive the base flow signature. The first step in hydrograph analysis entails separation of stream flow into the two major components: surface runoff and base flow (Arnold et al., 1995). However, the exact separation of each component is often arbitrary and based on either the use of standard methodologies cited in the literature (McCuen, 1989). All methods suffer from the lack of real knowledge of how the water moves through the watershed over time for a multitude of storm events and antecedent moisture conditions (Arnold et al., 1995).

Numerous analytical methods have been developed to separate base flow from total stream flow (McCuen, 1989). Although most procedures are based on physical reasoning, elements of all separation techniques are subjective. Manual separation of stream flow hydrograph into surface flow and ground water flow is difficult and inexact; often results derived from such manual methods cannot be replicated among investigators (White and Sloto, 1990). Attempts to automate the manual methods with the computer remove some of the subjectivity inherent in these methods and substantially reduce the time required for analysis of stream flow records (White and Sloto, 1990). According to Arnold et al. (1995), an automated base flow separation technique has been developed and tested. Base flow is considered to be the ground-water contribution to stream flow. Estimates of the amount of base flow can be derived from stream flow records. Such estimates are critical in the assessment of low flow characteristics of stream for use in water supply, water management, and pollution assessment. An automated technique was developed to calculate the slope of the base flow recession curve from the stream flow records. This technique is an adaptation of the Master Recession curve procedure (Arnold et al., 1995).

The base flow filter can be passed over the stream flow data three times (forward, backward and forward), depending on the user's selected estimates of base flow from pilot studies of stream flow data.

2.5 Sensitivity Analyses, Calibration and Validation of SWAT Model

The ability of a watershed model to sufficiently predict water quantity and quality for a specific application is evaluated through sensitivity analysis, model calibration, and model validation.

2.5.1 Sensitivity analyses

Sensitivity is measured as the response of an output variable to achange in an input parameter, with the greater change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model (White and Chaubey, 2005). It is a necessary process to identify key parameters and parameter precision required for calibration (Ma et al., 2000). SWAT is acomplex model with many parameters that makes manual calibration difficult. Hence, sensitivity analysis was performed to limit the number of optimized parameters toobtain agood fit between the simulated and measured data. Sensitivity analysis helps todetermine the relative ranking of which parameters most affect the output variance due toinput variability (Van Griensven et al., 2002) which reduces uncertainty and provides parameter estimation guidance for the calibration step of the model. Spruill et al. (2000) performed a manual sensitivity analysis of15 SWAT input parameters for a 5.5 km^{2}watershed in Kentucky, which showed that saturated hydraulic conductivity, alpha base flow factor, drainage area, channel length, and channel width were the most sensitive parameters that affected stream flow.

Numerous sensitivityanalyseshave been reported in the SWAT literature, which provide valuable insights regarding which input parameters have the greatest impact on SWAT output. A two-step sensitivity analysis approach is described by Francos et al. (2003), which consists of: (1) a “Morris” screening procedure that is based on the One factor at a time (OAT) design, and (2) the use of a Fourier amplitude sensitivity test (FAST) method.

The screening procedure is used to determinethe qualitativeranking of an entire input parameter set for different model outputs atlow computationalcost, while the FAST methodprovides an assessment of the most relevant input parameters for a specific set of model output. Holvoet et al. (2005) presented the use of a Latin hypercube (LH) OAT sampling method, in which initial LH samples serve as the points for the OAT design.

The LH-OAT method has been incorporated as part of the automatic sensitivity/calibration package included in SWAT 2005 (Gassman et al., 2007).

Therefore, sensitivity analysisasan instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Hamby, 1994). The sensitivity analysismethod inthe ArcSWAT interface combines the Latin Hypercube (LH) and One factor-At-a-Time (OAT) sampling (Van Griensven, 2005).

2.5.2 Calibration approach

Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two. The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman et al., 2007). Coffey et al. (2004) presented nearly 20 different statistical tests that can be used for evaluating SWAT streamflow output during amanual calibration process. They recommended using the Nash-Sutcliffe simulation efficiency ENS and regression coefficients $r^2$for analyzing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by Spruill et al. (2000). Eckhartd and Arnold (2001) outlined the strategy ofimposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT. Subsequently, an automatic calibration of the version SWAT-CUP of the SWAT model with a stochastic global optimization algorithm and Shuffled Complex Evolution algorithm is presented for amesoscale catchment.

Automated techniques involve the use of Monte Carloor other parameter estimation schemes that determine automatically what the best choice of values are for asuite of parameters, usually on the basis of a large set of simulations, for a calibration process (Gassman et al., 2007). Automatic calibration involves the use of asearch algorithm to determine best-fit parameters. It is desirable as itis less subjective and dueto anextensive search of parameter possibilities can give results better than if done manually. The manual trial-and-error method of calibration is the most common and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite (Refsgaard and Storm, 1996). However, it is very cumbersome, time- consuming, and requires experience.

2.5.3 Validation

In order to utilize any predictive watershed model for estimating the effectiveness of future potentialmanagement practices the model must be first calibrated to measureddataand should then be tested(without further parameter adjustment) againstan independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set perform reasonably well on an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios (Dilnesaw, 2006).

2.6 Weather Generator

Lack of full and realistic long period climatic data is the problem of developing countries. Weather generators solve this problem by generatingdata having the same statistical properties as the observed ones (Danuso, 2002). SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The user may choose to read these input from a file or generate the values using monthly average data summarized over a number of years.

SWAT includes the WXGEN weather generator model (Sharpley and Williams, 1990) to generate climatic data or to fill in gaps in measured records. The occurrence of rain on a given day has a major impact on relative humidity, temperature and solar radiation for the day.

The weather generator first independently generates precipitation for the day (Neitsch et al., 2005). Once the total amount of rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green and Ampt method is used for infiltration. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently (Neitsch et al., 2005).

2.6.1 Precipitation

The daily precipitation generator is a Markov chain-skewed (Nicks, 1974) or Markov chain exponential model (Williams, 1995). A first-order Markov chain is used to define the day as wet or dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount.

2.6.2 Occurrence of wet or dry day

With the first-order Markov-chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.1 mm of rain or more. The user is required to input the probability of a wet day on day i given a wet day on day i – 1, Pi(W/W), and the probability of a wet day on day i given a dry day on day i – 1, Pi(W/D), for each month of the year. To define a day as wet or dry, SWAT generates a random number between 0.0 and 1.0. This random number is compared to the appropriate wet-dry probability, Pi (W/W) or Pi (W/D). Ifthe randomnumber is equalto or less than the wet-dry probability, the day is defined as wet. If the random number is greater than the wet-dry probability, the day is defined as dry.

2.7 Agricultural Water Demand

The exploitation of natural resources for agricultural production is limited due to insecurity, displacement of communities, degraded irrigation infrastructure and lack of technical support, inputs, marketing and market access (SWALIM, 2011). However the basin has been facing an enormous challenge on use and protect in this limited water resource.

Agriculture is an important activity in terms of food security, economic activity and water use. Irrigated agriculture, moreover, plays a disproportionately important role because it is generally two to three times more productive than rain-fed agriculture, and because irrigation uses approximately 70% of the region's water supplies.

2.8 Case study related to the study

- **Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, south eastern Ethiopia (A.A. Shawul. et al, (2013)).**

It was found that the model has strong predictive capability with r^2, ENS and D values of 0.76, 0.75 and 3.30, respectively. Statistical model efficiency criteria fulfilled the requirement of $r^2 > 0.6$ and ENS > 0.5 which is recommended by SWAT developer (Santhi et al., 2001). This showed the model parameters represent the processes occurring in the watershed to the best of their ability given available data and may be used to predict watershed response for various outputs. The SWAT model estimated other relevant water balance components in addition to the daily and monthly discharge of the watershed. Average annual basin values for different water balance components during a base simulation periods shows average annual watershed gain and losses with change in soil water storage.

- **Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT. (Ayivi, F., & Jha, M. K 2018).**

The statistical evaluation revealed a strong correlation between the measured and simulated values, as indicated by the R^2 and NSE values that ranged between 0.9 and 0.91. The SWAT model estimated other important water balance components in addition to the monthly discharge of the watershed. Water yield is one of the important parameters estimated by the model for efficient water management and planning of the study area. The contribution made by each sub-watershed in the watershed area to the total water yield during the simulation period was examined using the calibrated model.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the study Area

3.1.1 Location

Gidabo watershed is located in the Abaya-Chamo sub-basin of the Rift Valley Lakes Basin situated in the southern part of the country within the administrative Regions of Oromiya and SNNP Region. To be more specific, it falls in Abaya district of Borena zone of Oromia region and Dale district of Sidama zone of SNNPR (near Dilla town to east of Lake Abaya). It lies approximately between 6°14' - 6° 92' N latitude and 38° 02' - 38°65'E longitude, at elevation ranges of 1171 - 3213 m.a.s.l. The Gidabo River has many perennial tributaries originating from the Sidama mountain peaks. The upper part of the catchment is covered with thick bushes and shrubs. However middle catchment is occupied with small and scattered bushes and grasses. The lower part mainly comprises of delta and swamp area and is covered with tall grasses.

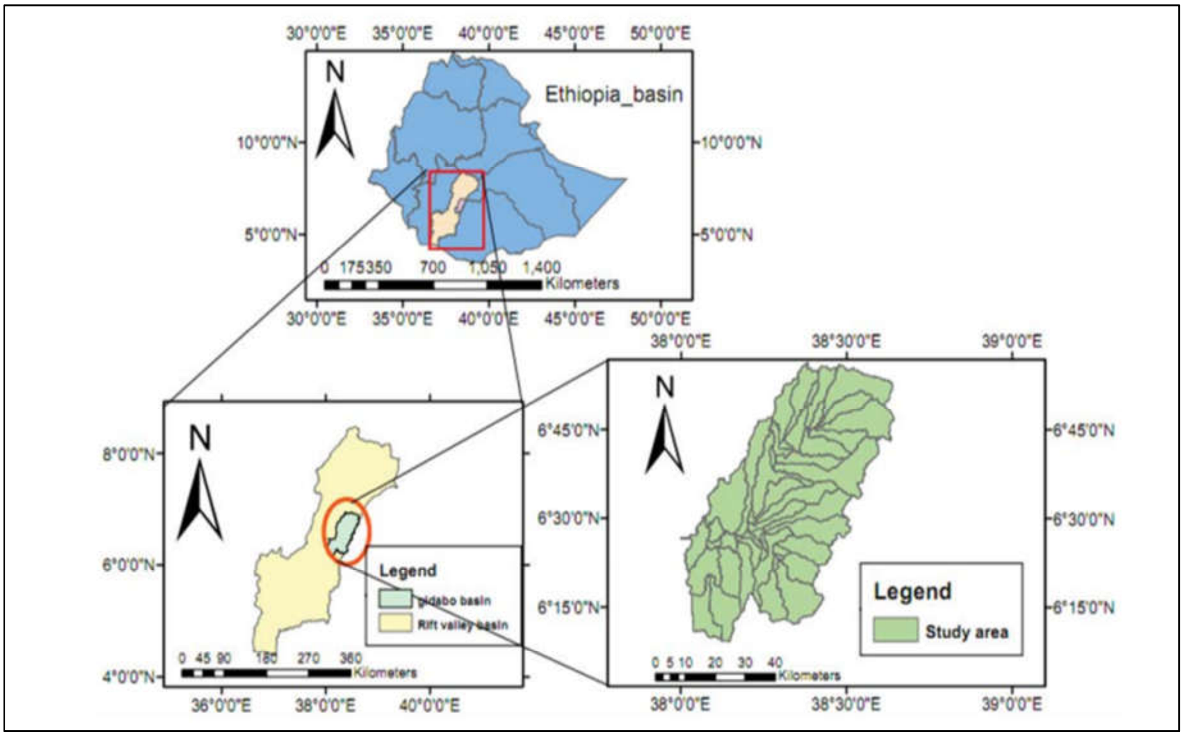


Figure3. 1: Location map of the study area; (source Ethiopian river basins map)

3.1.2 Climate of study area

Gidabo watershed falls within the traditional Kola agro-climatic zone, which can be classified as semi-arid in the lower part and humid in the upper part. The climatic data are recorded from the four observational stations: Dilla, Aleta-wondo, Yirgalem, Morocho located near by the watershed. The average minimum temperature varies from 10.24^{o}C in Dec to 12.32^{o}C in July and the maximum temperature ranges from 25.88^{o}C to 30.52^{o}C in February.

In the highlands and escarpment bounding the rift floor precipitation exceeds 1,600 mm/year, whilst at the lowest altitude in the rift floor precipitation is often below 800 mm/year. Precipitation is characterized by a bimodal pattern with maximum peaks during April and May ("small rainy" season) and during September and October in the "main rainy" season (Abraham Mechal, 2015, page 17).

The mean monthly sunshine hours in the project area varies from 3.3 hours/day in July to 7.71 hours/day in January. In general, the sunshine hours are favorable for crop production mainly cereal and sugar crops.

The mean monthly relative humidity in command varies from 56.19% in February to 80.33% in September influencing the evaporation, disease prevalence, crop maturity etc.

The wind speed at an elevation of 2m influences the evaporation and evapotranspiration indicating the crop water requirement. The average wind speed varies from 0.39 m/sec in July to 0.7 m/sec in March. The daily estimated reference evapotranspiration values ranges from 2.96 mm in July to 4.62 mm in March.

3.1.3 Land use/cover and Soils

Land use/cover:

The land use/cover and soil data obtained from the Ministry of Water Resources of Ethiopia were used for parameterizing the SWAT model. The land uses were divided into eleven major groups: Forest-Ever Green (FRSE), Forest-Deciduous (FRSD), Agricultural Land Generic (AGRL), Range-Brush (RNGB), Forest-Mixed (FRST), Range-Grasses (RNGE), Wetland-non-forested (WETN), Agricultural Land-Row Crops (AGRR) Water (WATR), Residential (settlement) (URBN)and Barren (Bare land) (BARR). Each of these cover types are tremendously influenced by properties of landform, soils and climate as elsewhere in Ethiopia. The major land using activities in the watershed are rainfed crop production; livestock raising that involves nature conservation and wood cutting while the minor land uses are planting trees mostly in the upstream areas of the watershed. The swamp and marshland is located at the lower part of the watershed.

Soils:

The soil classification was carried out according to the World Reference Base for Soils Resources. According to this classification most of the soils of Gidabo area fall in six major units, i.e. Chromic Luvisols, Eutric Leptosols, Eutric Vertisols, Haplic Luvisols, Humic Nitisols, Lithic Leptosols. The most extensive soils are Eutric Leptosols which cover about 29.63% of the area. About 26.03% area has Lithic Leptosols which are subjected to water-logging. Chromic Luvisols are moderately drained soils which are found on relatively levelled areas and account for about 10.68% of the area. The remaining area is occupied by miscellaneous types of soils.

3.2. Data Availability

3.2.1. Meteorological data

The required long term daily precipitation for Dilla, Aleta-wondo, Yirgalem and Morocho stations (Figure 3.2) and daily maximum and minimum temperature of Dilla station (Figure 3.3) were collected from National Meteorological Service Agency (NMSA) of Ethiopia for 25 years (1990 – 2014).

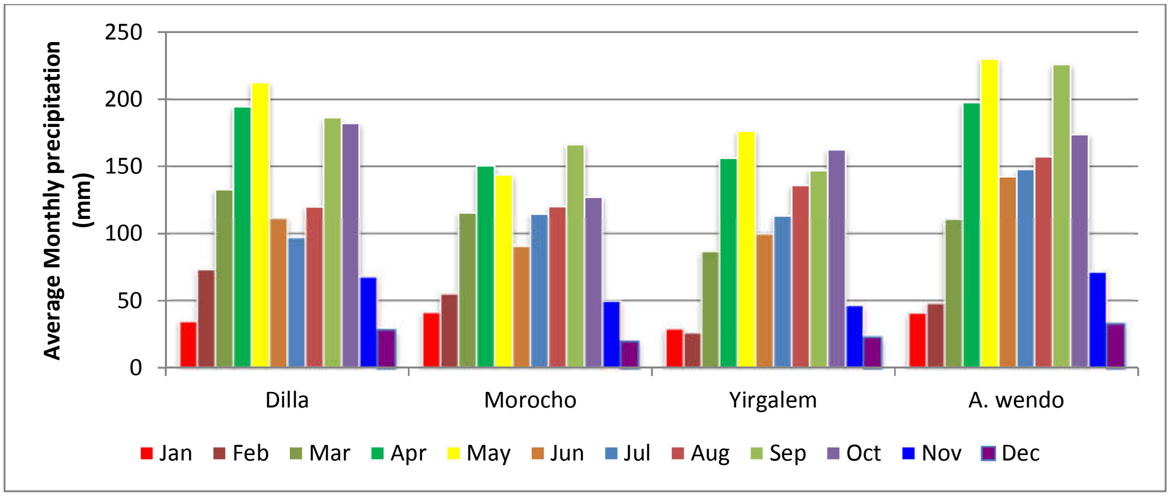


Figure 3. 2: Long term mean monthly precipitation of specified stations

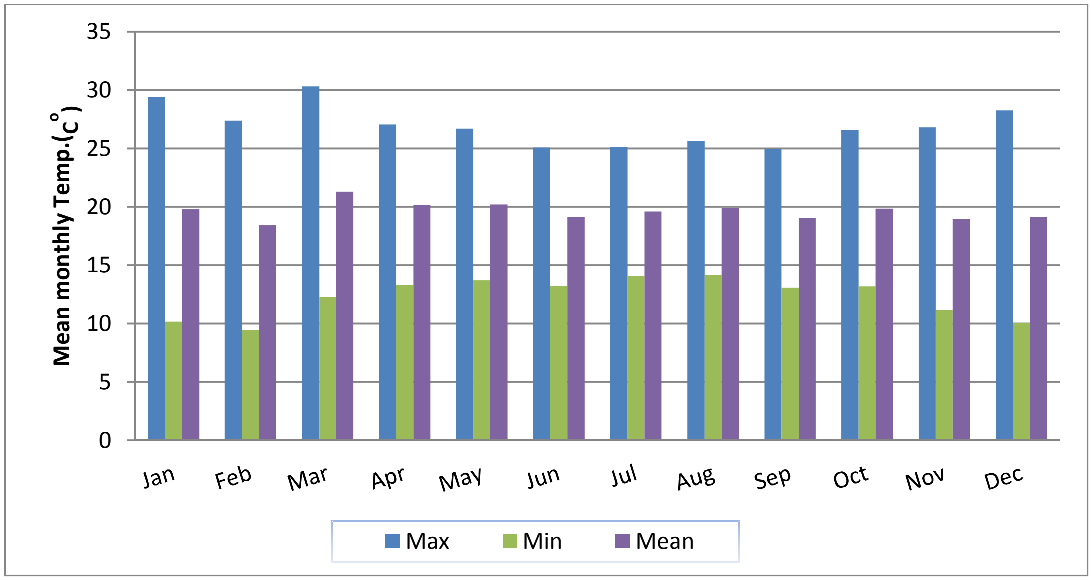


Figure3. 3: Dilla Long term average monthly maximum, minimum and mean temperature.

The rest weather elements (wind speed, relative humidity and sunshine hours) were also obtained from Dilla station which is a synoptic of the study area (Figure: 3.4). Daily solar radiation was calculated from the daily sunshine hour data using the Angstorm-Prescott equation (eqn.3.1.), which relates short-wave radiation with other physical factors, such as extra-terrestrial radiation, optical air mass, and turbidity, water vapour content of the air, amount and type of cloud cover (Biniam, 2009; White, 2009).

Qs = Qext (a+b n/12)………………………………………………………………….... (3.1)

where Qs is the solar radiation in W/m2, Qext is the daily total extra-terrestrial radiation in W/m2, **a** and **b** are constants which depend on the location, season, and state of the atmosphere, n is the actual number of hours of bright sunshine (sunshine hour), and 12 is the number of day light hours since Ethiopia is near the Equator, it is assumed to be 12.

3.2.2. Hydrological data

Daily river discharge data of the Gidabo river watershed for about 25 years (1990-2014) were obtained from the Hydrology Department of the Ministry of Water, Irrigation and Electricity, Ethiopia (MoWIE). It was used for performing sensitivity analysis, calibration and validation of the model. The hydrology of the Watershed reflects the rainfall pattern with river flow peaking firstly in April and subsequently in October (Figure. 3.4).

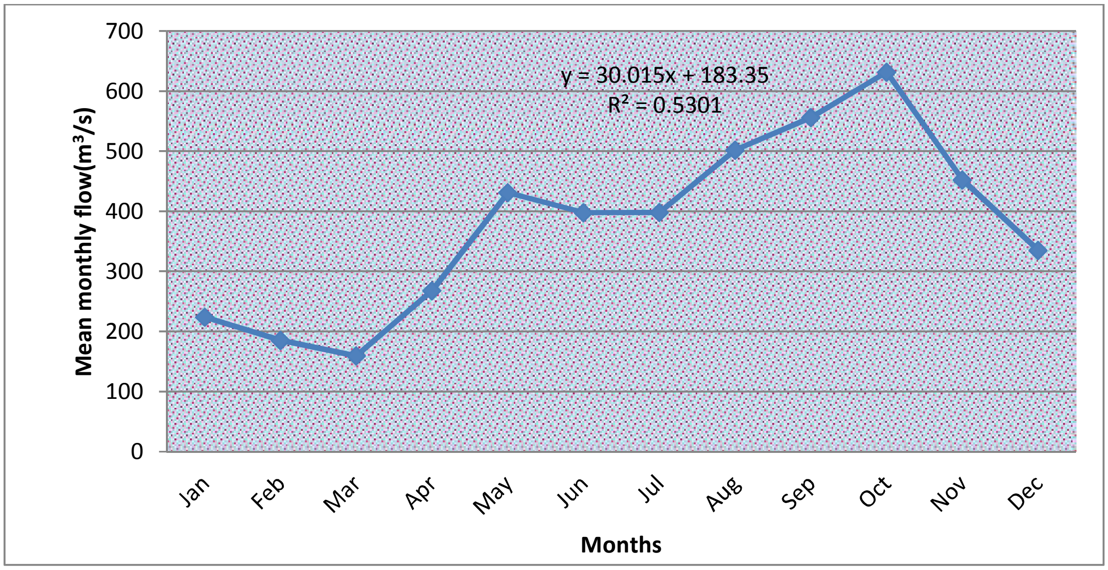


Figure3. 4: Mean monthly runoff at Gidabo River gauging station (meassa station)

3.2.3 Spatial data

The physical data of the area can be obtained from the topographic map of the area available for mapping agencies or specific studies conducted in the respective areas. To delineate the watershed and sub-basins and to determine stream networks SWAT was used the digital representation of the topographic surface i.e. Digital elevation model (DEM). The DEM forms the base to delineate the watershed boundary, stream network and create sub-basins. This is being performed by the pre-processing module of the SWAT but will require a so called minimum threshold area. Topography is defined by a DEM which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. It is also use to analyse the drainage patterns of the land surface terrain. And sub-basin parameters such as slope, slope length, and defining of the stream network with its characteristics such as channel slope, length, and width was derived from the DEM.

3.3 Material used

Different materials were used to conduct this research for different purposes to the same final output as depicted in table form (Table 3.1)

Table3. 1: Materials used.

Name	Function (Application area)
Note book and pen	- To take a note - To have a necessary information regarding to this study
Microsoft office word (window 10)	- To write, edit and organise this research and related relevant data - To present results and check uncertainty
Microsoft office excel (window 10)	- To prepare data including graphs - To arrange data as it is necessary - To calculate a required simple parameters - To visualizing and analysing hydro-metrological data
Arc GIS 10.1	- GIS software used for spatial analysis of hydrological and physical parameters
SWAT 2012	- An ArcGIS interface of soil and water assessment tool used for simulation.
SWAT-CUP	- A sensitivity analysis program interface of SWAT and used for calibration, sensitivity analysis, uncertainty measures and validation.
PCPstata	- Used to prepare data for weather generator
DEW02	- Used to prepare data for weather generator by using minimum and maximum temperature and relative humidity
RAINBOW	- To test the homogeneity of hydro-metrological data
DEM(30m*30m)	- Digital elevation model of 30m*30m spatial resolution for stream delineation.
Meteorological data	- Rainfall, Temperature (max. and min), solar radiation, relative humidity, wind speed. It is used as an input data for SWAT simulation.
Hydrological data	- Stream discharge data. Used for calibration and validation
Physiographic data	- Soil and Land use/cover data for the preparation of hydraulic response unit and simulate the model
CROPWAT8.0	- To calculate crop water requirements through the catchments.

3.4 Methods

The “Soil and Water Assessment Tool” SWAT (Arnold et al., 1998) and the calibration and uncertainty program “Sequential Uncertainty Fitting Algorithm version 2’’ SUFI-II (Abbaspour et al., 2004, 2007) were applied to the Gidabo watershed. SWAT is a physically based long-term continuous time watershed-scale model developed initially to predict the impact of agricultural or land management practices on water, sediment and agricultural chemical yields in large complex watersheds. It is also capable of predicting water yield, nutrient, and sediment loading under climate-change scenarios (Neitsch et al., 2011). SWAT is a semi-distributed model operating on a daily time-step. A high level of spatial variability can be simulated, since SWAT allows the division of the watershed into a large number of sub watersheds, which are then further subdivided into unique combinations of soil, land use and slope characteristic areas called hydrological response units (HRUs). The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The HRUs are defined by means of a coupled GIS (geographical information system) tool based on a digital elevation model (DEM), land cover and soil maps. The water balance is the main driving force in SWAT. For each HRU the water balance is represented by five storage components: canopy interception, snow, soil profile, shallow aquifer, and deep aquifer.

The hydrological processes simulated by SWAT include precipitation, interception, infiltration, surface runoff, evapotranspiration, percolation, and lateral subsurface flow within both the soil and the aquifer (Arnold et al., 1998; Neitsch et al., 2011). Surface runoff was estimated using a modified Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972). Due to a lack of sufficient climate data, the Hargreaves method (Hargreaves and Samani, 1982) was applied to estimate potential evapotranspiration (PET) instead of the more data-demanding Penman–Monteith (Allen, 1986; Allen et al., 1989; Monteith, 1965) and Priestley–Taylor (Priestly and Taylor, 1972) methods available in SWAT. Oudin et al. (2005) demonstrated that rainfall runoff models using such parsimonious temperature-based methods may perform similarly well or even better in terms of model fit than more data-demanding approaches. Nevertheless, the accuracy of the PET calculation deserves further consideration, particularly with regard to the semi-arid parts of the model area.

The excess water available after initial abstractions and surface runoff infiltrates into the soil. The soil profile is subdivided into several layers. Percolation is simulated for each layer in the soil profile. When the soil water in the layer exceeds field capacity, downward flow occurs and its rate is governed by the saturated hydraulic conductivity. The flow through each soil layer is simulated using a storage routing technique. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation using a kinematic storage routing technique based on slope, slope length, and saturated conductivity. SWAT partitions groundwater into two aquifers systems: a shallow aquifer which contributes return flow to streams within the watershed and a deep aquifer which contributes to return flow to streams outside the watershed. The recharge is accordingly subdivided into shallow and deep aquifer recharge. Neitsch et al. (2011) describe the implementation of the above-mentioned hydrological processes in SWAT in more detail.

Calibration and validation is performed by SWAT-CUP (Calibration and Uncertainty Program) using the SUFI-2 algorithm, as it represents uncertainties of all sources (e.g., data, model, etc.) (Yang et al., 2008) and can perform parameter sensitivity analysis to identify those parameters that contribute most to the output variance. A comprehensive description of the SUFI-2 algorithm can be found in Abbaspour et al. (2011). Since the SWAT model is calibrated using measured stream flow data, the recharge estimation is based on surface-water studies and numerical modelling according to the classification by Scanlon et al. (2002). Thus, recharge is estimated as a residual term in the water balance equation. Therefore, the accuracy of the estimate is controlled by the accuracy of the measured water balance components.

3.4.1 Data Collection

In order to conduct the research data was collected through secondary data to have good perception on the catchment area (land use/land cover, soil, slope), river morphology.

Secondary data

Different type of data such as hydrological (stream-flow) and meteorological (rainfall, temperature, wind speed, relative humidity, sunshine hours) were collected from Ministry of Water, Irrigation and Energy of Ethiopia (MoWIE) and National Meteorological Agency of Ethiopia (NMA) respectively. Those data were the daily data with some missing due to different reason (carelessness, instrumental problem, change of location for station, climate variability).

3.5. Data Analysis

3.5.1 Hydro-Metrological Data

The hydro-meteorological data was well prepared and some missing data of the synoptic (self-record) station was filled with negative (-99.0) for weather generator. This values (-99.0) tells SWAT to generate weather data for that missed value and for other stations which is not synoptic.

Followed by the collection of primary and secondary data; the procedure of SWAT model was undergone step by step up to simulation (new project, watershed delineation, HRU definition, write input data, edit input data, simulation) and then after SWAT model was run; SWAT-CUP procedure was continued to perform sensitivity, calibration, validation and uncertainty in order to get a final output of the study.

The general procedure of the study was conceptually illustrated as a flow chart in figure 3.5.

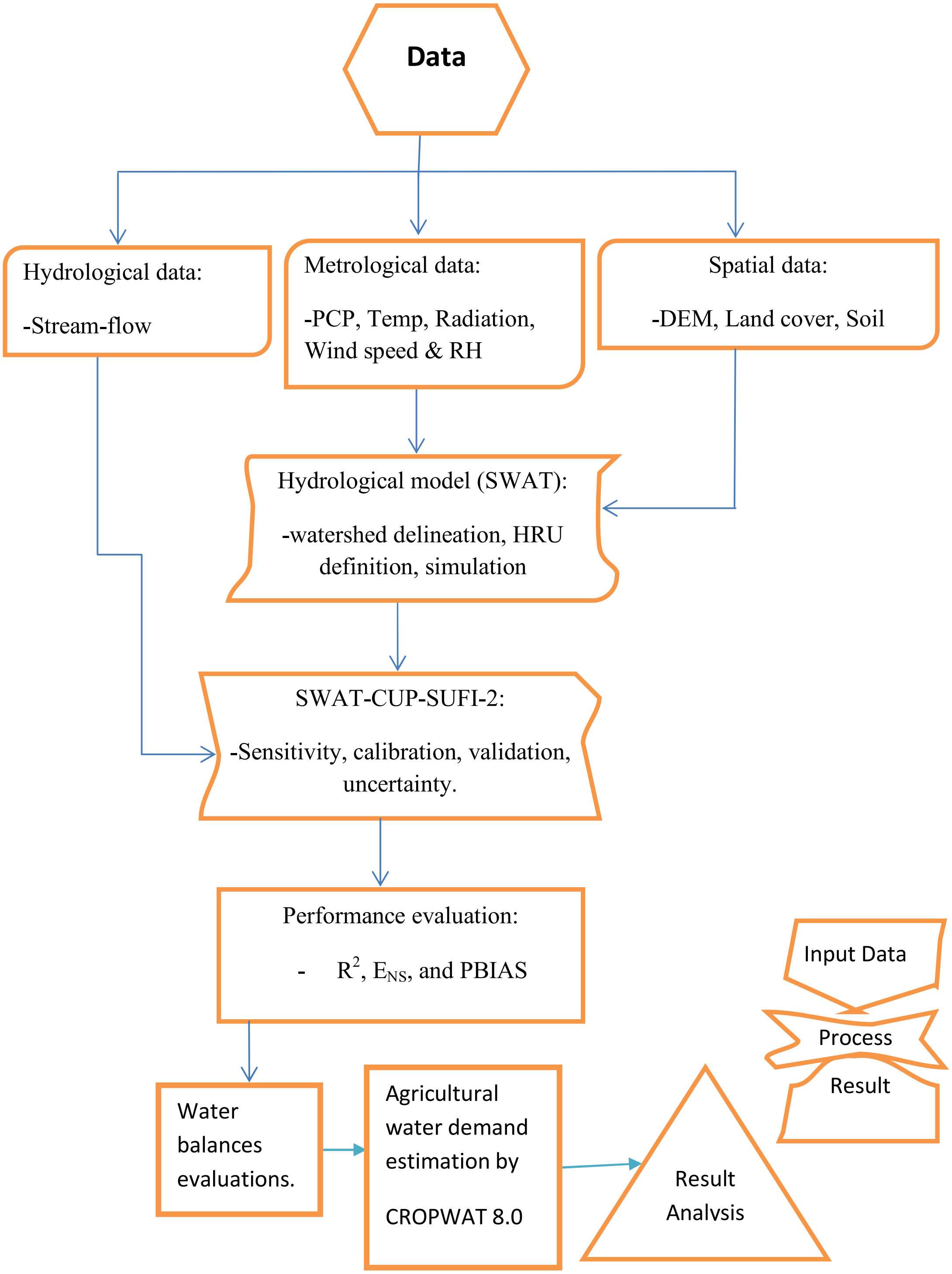


Figure3. 5: Flow chart of the study.

3.5.2. Precipitation Data Quality and Consistency checking

3.5.2.1. Consistency test

The consistency of data were analysed based on the theory that a plot of two cumulative quantities that are measured for the same time period and their proportionality remain constant which is represented by the slope consistency was checked by using double mass curve. In this study station of Aleta Wendo, Morocho, Yirgalem and Dilla were used. Only Morocho station was needed for the adjustment of slope and adjusted accordingly (fig: 3.5) and other stations are consistent originally.

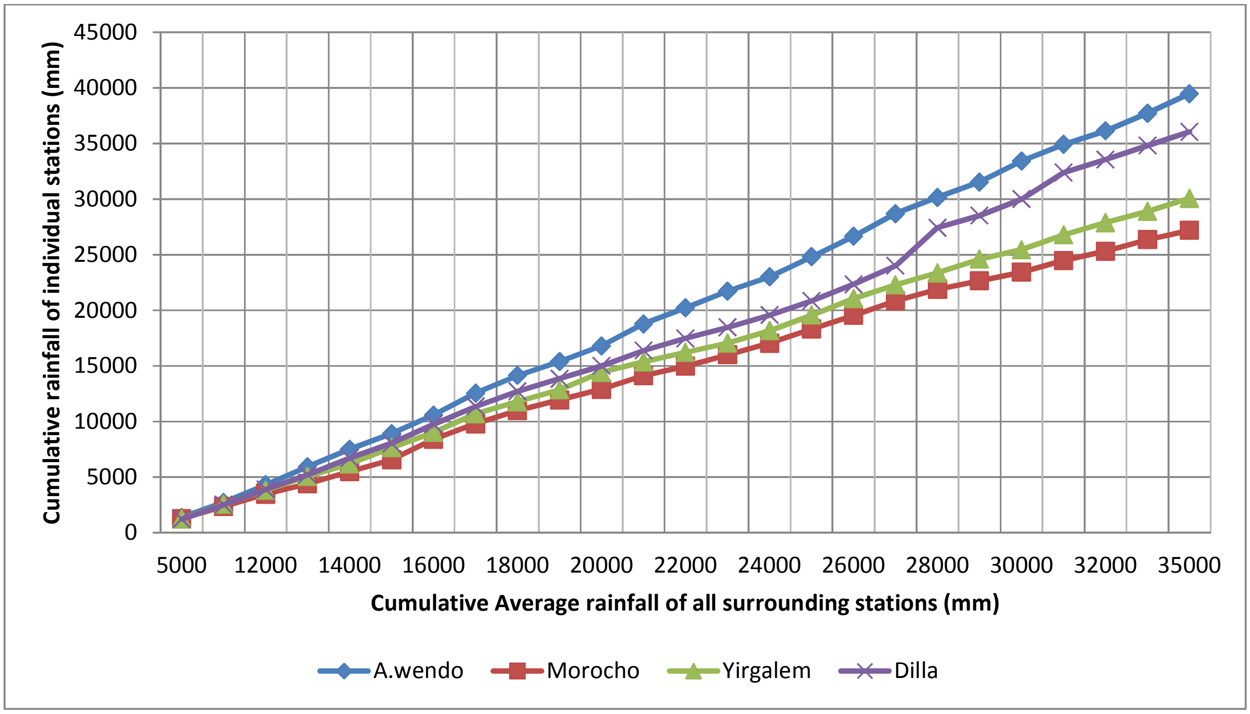


Figure3. 6: Double mass curve based consistency test of precipitation

3.5.2.2. Homogeneity test

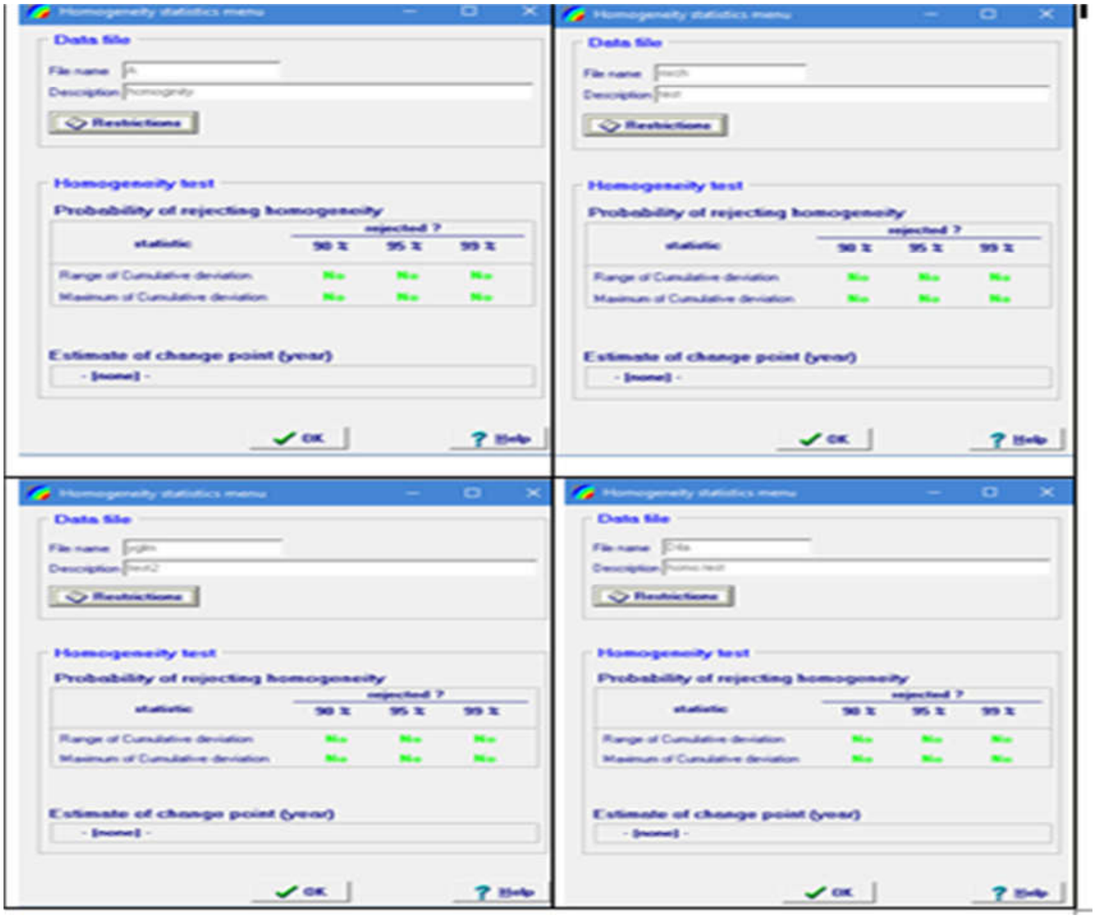
Nonhomogeneous data series for climate change impact assessment may amplify real climate variations. Collected data said to be homogeneous if the measurements have been consistency done by the same method, the same instrumentation, at the same time and place and within the same environment. Homogeneity test was evaluated by using RAINBOW software in a means of frequency analysis since it's one of the methods designed to study the homogeneity of hydro-metrological datasets (Raes, D., 2016).

The restriction of homogeneity assures that the observations are from the same population. One of the tests of homogeneity is based on the cumulative deviations from the using:

$$S_k = \sum_{i=1}^{k} (A_i - \bar{A}) \text{..........} k = 1 \ldots n \text{ ....} \quad (3.2)$$

Where; A_i is time series data records from A1, A2, and A3; and $\bar{A}$ is mean of the data. The initial value of S ($_{k=0}$) and last value of S ($_{k=n}$) are equal to zero.

For a homogeneous record, one may expect that the S_k ''s fluctuates around zero since there is no systematic pattern in the deviations of the S_k ''s from their mean value. If the cumulative deviation crosses one the horizontal lines the homogeneity of the data is rejected with respectively90, 95 and 99% probability. The probabilities of rejecting the homogeneity of the datasets were evaluated for this study using the homogeneity statistics menu. The homogeneity test was done after several trials for precipitation stations (Aleta wendo, Morocho, Yirgalem and Dilla) used in the study and the result were achieved by using RAINBOW software (fig: 3.7)



Probability of rejecting homogeneity

statistic	rejected ? 90 %	 95 %	 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- [none] -

Figure3. 7: Homogeneity test of precipitation by rainbow

3.6. SWAT Hydrological model selection

SWAT (Soil and Water Assessment Tool) was a best required modelling tool by having many reasons. The first and for most, it is a public domain model and it is used for free. Secondly in countries like Ethiopia, there is a shortage of long-term observational data series to use other sophisticated models; therefore SWAT is computationally efficient and requires minimum data in this case. Due to this reason several researchers have used SWAT model in Ethiopia.

For instance, Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, south eastern Ethiopia (A.A Shawul, 2013). Mengistu and Sorteberg (2012) used the SWAT model to investigate the sensitivity of SWAT simulated stream flow to climatic changes within the Eastern Nile River Basin. SWAT model capability and performance was checked in Lake Tana Basin and gave satisfactory results (Setegn et al, 2010). Based on the previous experiences of SWAT model obtained in Ethiopia and the above explained reasons the SWAT model is preferred for this particular study.

3.7 Hydrological Components of SWAT

The simulation of hydrology of a watershed in SWAT is done with two separate divisions. The first one the land phase of the hydrological cycle that controls the movement of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediment, nutrients, and organic chemicals through the channel network of the watershed to the outlet.

3.7.1 Land Phase of Hydrological Cycle

Under this cycle, SWAT simulate the hydrological cycle based on the water balance equation

$$\mathrm{SWt} = \mathrm{SWo} + \sum_{i=1}^{t}(Rday - Qsurf - ETa - Wseep - Qgw) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, SWt is the final soil water content (mm), SWo is the initial soil water content on day i (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), ETa is the amount of evapotranspiration on day i (mm), Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), and Qgw is the amount of return flow on day i (mm).

The amount of soil water is usually measured in terms of water content as a percentage by volume or mass, or as soil water potential, this soil water content is highly depending on the water balance values given in above equation (3). Mostly, taking the precipitation as a source of soil water content and reduction of runoff, actual evapotranspiration, and ground water from precipitation is result in the availability of water in the soil. So SWAT model revealed quantitatively the value of soil water content (SW) depends on the above water balance values.

However, water content by itself doesn't how necessarily describe the availability of water to the plants, indicates how the water moves within the soil profile. The only information provided by soil water content is the relative amount of water in the soil.

Percolation - is the downward movement of water in the soil. SWAT calculates percolation for each soil layer in the profile. Water is allowed to percolate if only the water content exceeds the field capacity of that layer (Neitsch et al., 2005).

Surface runoff - occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure and Green and Ampt infiltration method. Using daily or sub-daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. In case of this particular research SCS curve number method is used to estimate surface runoff due to unavailability of sub-daily data for Green and Ampt method.

Lateral flow - is common in areas with high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturate zone stored above this layer. This is called perched water table, which is the source of water for lateral subsurface flow (Neitsch et al. 2005).

Peak discharge is the maximum volume flow rate passing a particular location during a storm event. SWAT calculates the peak runoff rate with a modified rational method.

$$q_{peak} = \frac{\alpha tc * Qsurf * A}{3.6 * tconc} \text{...} (4)$$

Where: q peak is the peak runoff rate (m^3/s), α_{tc} is the fraction of daily rainfall that occurs during the time of concentration, Qsurf is surface runoff (mm), A is the area of the sub-basin (km^2), $t_{conc}$is the time of concentration (hr) and 3.6 is a conversion factor.

Potential evapotranspiration: many methods there to estimate potential evapotranspiration (PET). Only three methods are incorporated into SWAT: Penman-Monteith method, Priestley-Taylor, and Hargreaves method.

The FAO Penman-Monteith method is recommended as the only ETo method for determining reference evapotranspiration when the standard meteorological variables including air temperature, relative humidity, and sunshine hours are available (Allen RG et al, 1998). In this particular study the potential evapotranspiration for the study area was computed by FAO Penman-Monteith method.

The FAO Penman-Monteith method to estimate ETo can be derived:

$$\mathrm{ETo} = \frac{0.408\,\Delta(\mathrm{Rn}-\mathrm{G}) + \gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma\,(1+0.34u2)} \qquad (5)$$

WhereETo = reference evapotranspiration [mm day^{-1}],

Rn = net radiation at the crop surface [MJ $m^{-2}day^{-1}$],

G = soil heat flux density [MJ $m^{-2}day^{-1}$],

T= mean daily air temperature at 2 m height [°C],

u2 = wind speed at 2 m height [m s^{-1}],

es = saturation vapour pressure [kPa],

ea= actual vapour pressure [kPa],

es-ea = saturation vapour pressure deficit [kPa],

Δ = slope vapour pressure curve [kPa $°C^{-1}$],

γ = psychrometric constant [kPa $°C^{-1}$].

No weather-based evapotranspiration equation can be expected to predict evapotranspiration perfectly under every climatic situation due to simplification in formulation and errors in data measurement. It is probable that precision instruments under excellent environmental and biological management conditions will show the FAO Penman-Monteith equation to deviate at times from true measurements of grass ETo.

Ground water-the simulation of groundwater is partitioned into two aquifer system: unconfined aquifer (shallow) and confine (deep) aquifer in each sub basin. The unconfined aquifer contributes to flow in the main channel or reach of the sub-basin. Water that enters the deep aquifer is assumed to contribute to stream flow outside of the watershed (Arnoldet al, 1993). The water balance for a shallow aquifer is calculated with:

$$aq_{sh,i} = aq_{sh,i-1} + Wrchrg - Qgw - Wrevap - Wdeep - Wpump,sh \ldots\ldots(6)$$

where aqsh,i is the amount of water stored in the shallow aquifer on day i (mm), aqsh,i-1 is the amount of water stored in the shallow aquifer on day i-1 (mm), wrchrg is the amount of recharge entering the aquifer on day i (mm), Qgw is the groundwater flow, or base-flow, into the main channel on day i (mm), wrevap is the amount of water moving into the soil zone in response to water deficiencies on day i (mm), wdeep is the amount of water percolating from the shallow aquifer into the deep aquifer on day i (mm), and wpump,sh is the amount of water removed from the shallow aquifer by pumping on day i (mm).

3.7.2 The routing face of the hydrological cycle

The second phase of the SWAT hydrologic simulation is the routing phase, consists of the movement of water, sediment and other constituent (nutrient and pesticide) in the stream network. Open channel flow is defined as channel flow with a free surface, such as flow in a river or partially full pipe. SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model. The storage routing is based on the continuity equation:

$$\Delta V\ storage = V\ in - V\ out \ldots\ldots (7)$$

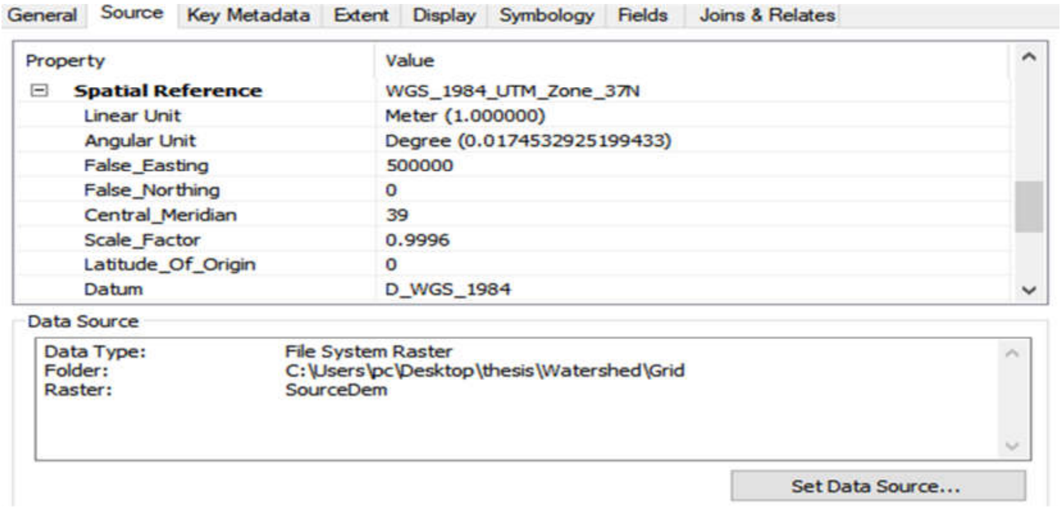
Where V storage is the change in volume of storage during the time step (m^3 water), V in is the volume of inflow during time step (m^3 water), V out is the volume of outflow during the time step (m^3 water). The detail of equation was briefly discussed in SWAT manual.

3.8 Model Set Up

3.8.1 Spatial data

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected in to the same projection called UTM Zone 37N, which is projection parameter for Ethiopia as shown in table 3.2 and figure 3.8. The SWAT model provides three spatial levels: the watershed, the sub-basins, and the HRUs. A watershed was partitioned into a number of sub-basins, for modelling purposes. The watershed and sub-basin delineation was done using DEM data. A mask was first created over the DEM around the study watershed, to reduce the processing time of the GIS functions. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. Outlet of the watershed was manually added to fix it at the river gauging station. About three fourth (3/4) of suggested threshold area by the ArcSWAT interface was used for the delineation of sub-basins to increase the number of sub-basins for a more detailed analysis of the hydrologic processes. The DEM was also used to analyse the drainage patterns of the land surface and also it was used to determine slope, slope length, channel slope and length.

Table3. 2: Transverse Mercator projection parameters used in the study area.



Property	Value
Spatial Reference	WGS_1984_UTM_Zone_37N
Linear Unit	Meter (1.000000)
Angular Unit	Degree (0.0174532925199433)
False_Easting	500000
False_Northing	0
Central_Meridian	39
Scale_Factor	0.9996
Latitude_Of_Origin	0
Datum	D_WGS_1984

Data Source

Data Type:	File System Raster
Folder:	C:\Users\pc\Desktop\thesis\Watershed\Grid
Raster:	SourceDem

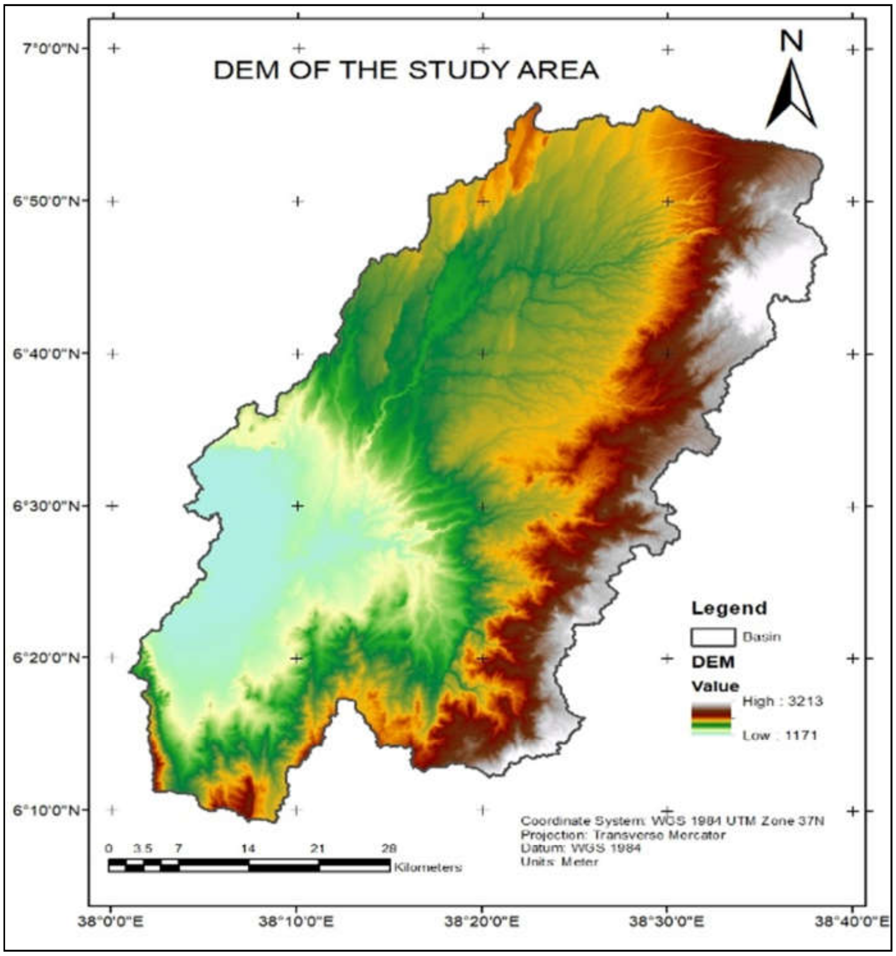


Figure3. 8: Digital Elevation Model of the study area (source: Rift Valley Basin, Hawassa, 2014).

3.8.2 Watershed delineation

From a minimum user defined threshold area of 8508.9312ha, and the watershed is divided into 27 sub-basins, where the total area of delineated watershed is reported by delineator as 3190.66 km^{2}as it is outlined in Figure 3.8. Each sub-basin boundary marks the end of reach, the end point of which the accumulation point for all flow from upstream which is then fed into downstream sub-basin and reach. Once the main reach and the longest paths/tributaries are formed, the model uses other physical parameters (soil, land use and land slope) to define HRUs. From the assumed threshold values for HRU delineation, we have found 200 HRUs in 27 sub-basins. Each HRU is composed of land use, soil type and slope parameters.

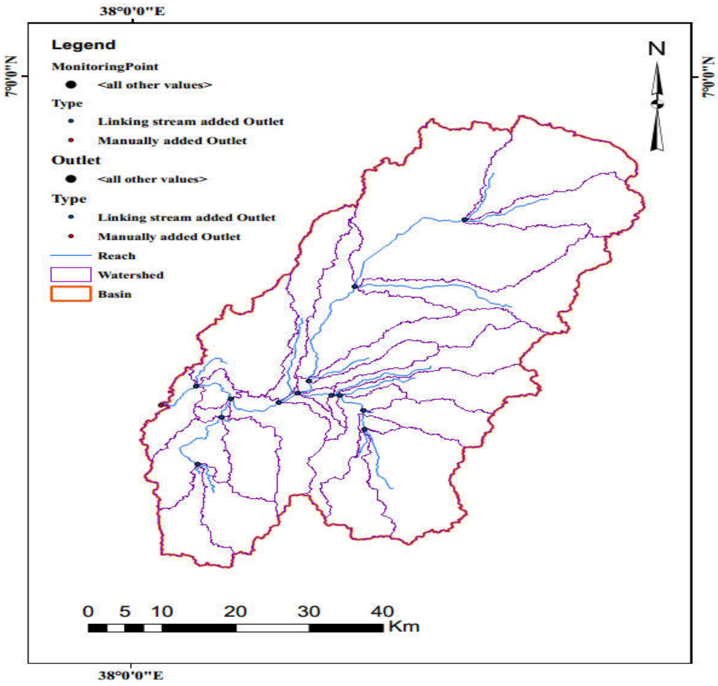


Figure3. 9: Delineated watershed of Gidabo River Basin showing topography and river network.

3.8.3 Land Use/Land Cover, Soil and Slope

Land Use/Land Cover: Land Use/Land Cover is the most important factors that affect surface erosion, runoff and evapotranspiration in a watershed. The Land Use/Land Cover map of the study area was obtained from Rift valley office, (2013) with resolution of 30m*30m.

As briefly illustrated in Table 3.3, the watershed is composed of eleven major land use types including its SWAT_ code, area coverage and percentage of watershed area.

Table3. 3 Land use/cover types as redefined by SWAT code and its corresponding area coverage

LANDUSE:	SWAT_ code	Area [km^2]	% Wat. Area
Forest-Evergreen	FRSE	470.87	14.76
Forest-Deciduous	FRSD	108.55	34.02
Forest-Mixed	FRST	294.93	9.24
Range-Grasses	RNGE	197.71	6.20
Range-Brush	RNGB	86.07	2.70
Agricultural Land-Row Crops	AGRR	620.46	19.45
Agricultural Land-Generic	AGRL	385.73	12.09
Wetlands-Non-Forested	WETN	5.78	0.18
Water	WATR	4.95	0.16
Residential (settlement)	URBN	35.08	1.10
Barren (Bare land)	BARR	3.60	0.11
Total		**3190.65**	**100**

.

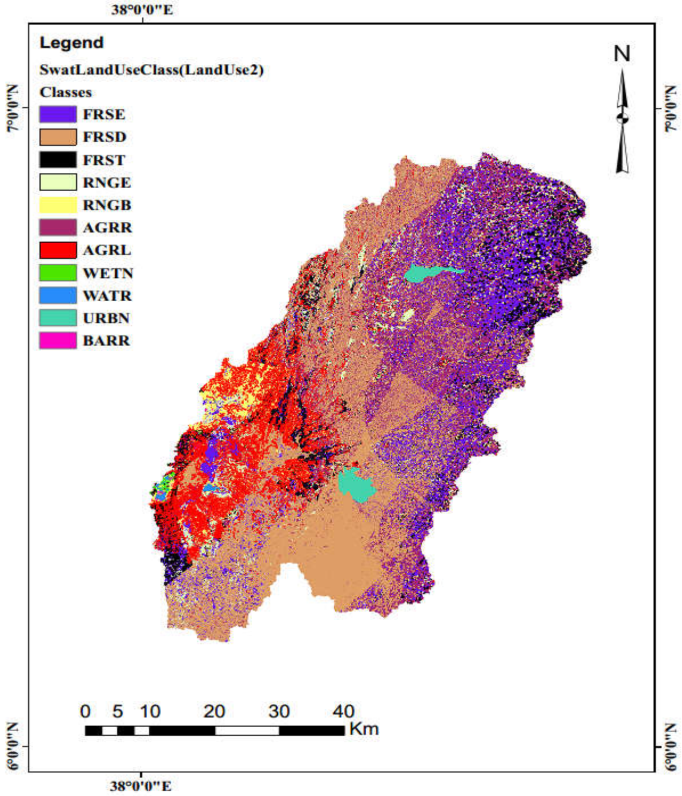


Figure3. 10: Land Use/Cover map of the study area (source: Rift Valley Lake Basin, 2013)

Soil: SWAT model basically needs the soil data in defining lumped land areas, HRUS. The SWAT soil database needs all the physical and chemical properties of each soil types in the watershed. Similar to that of land use/cover, soil map of the study area was obtained from MoWIE, which has a resolution of 30m*30m. User soil database was necessarily prepared in order to integrate the soil map within the SWAT model as mentioned below in the form of (Table 3.4).

Table3. 4 soil types of the study area with their area coverage

SOIL	Area [km^2]	% Wat. Area
CHROMIC LUVISOLS	340.89	10.68
EUTRIC LEPTOSOLS	945.45	29.63
EUTRIC VERTISOLS	137.45	4.31
HAPLIC LUVISOLS	210.23	6.59
HUMIC NITISOLS	725.01	22.72
LITHIC LEPTOSOLS	830.65	26.03
WATERBODIES	0.97	0.03
Total	**3190.65**	**100**

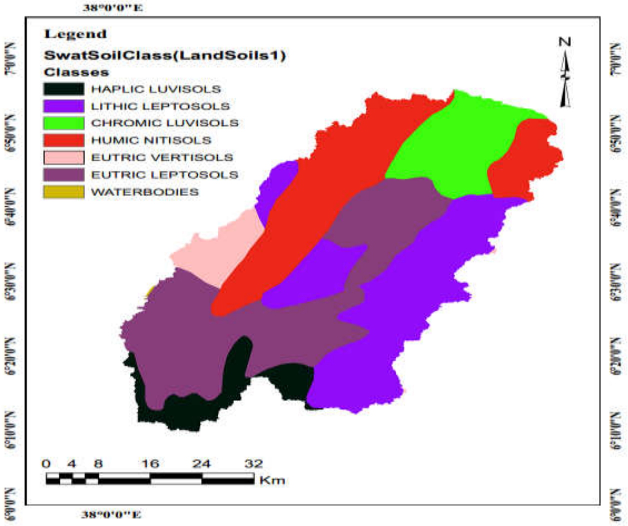


Figure3. 11: Soil map of the study area (source: MoWIE)

Slope: As the SWAT manual recommends, the slope of the study area was considered four classes of slope: 0 – 5%, 5 – 12%, 12 – 25%, and ≥ 25% (fig: 3.12). The maximum value of the slope ranges in SWAT database was assigned by default to be 9999%.

Table3. 5 Slope classification of the study area.

SLOPE (%)	Area (km^2)	% Wat. Area
0-5	262.45	8.23
5-12	851.04	26.67
12-25	1237.36	38.78
25-9999	839.80	26.32

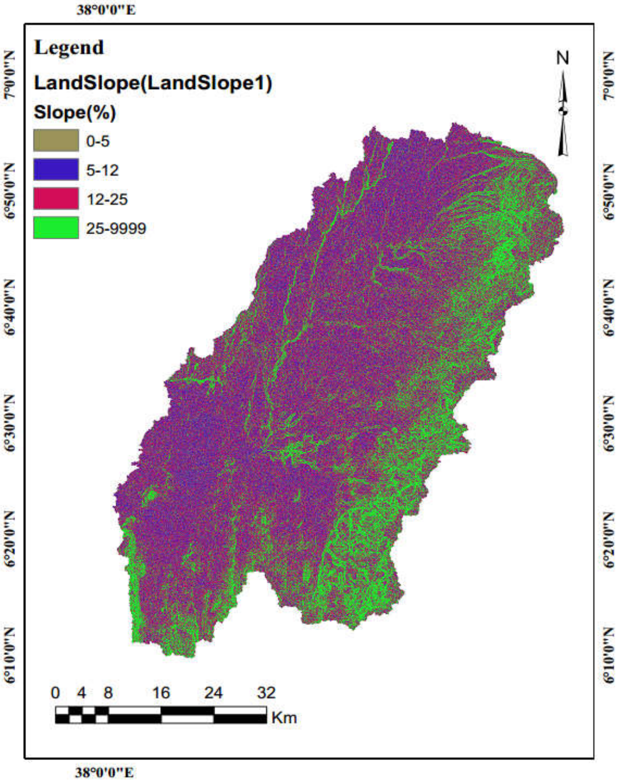


Figure3. 12: Slope classes of the study area

3.8.4 Hydrological Response Units Definition

The land area in a sub-basin was divided into HRUs. The HRU Analysis tool in ArcSWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by ArcSWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition.

The threshold level set for multiple HRU is a function of the project goal and the detail desired by the modeller (Neitsch et al., 2005). For this specific study a 20% threshold value for land use, 10% for soil and 20% for slope were used. The land use threshold level used was to eliminate minor land uses in each sub-basin. Land uses that cover a percentage (or area) of the sub-basin area less than the threshold level were eliminated. After the elimination process, the area of the remaining land uses was reapportioned so that 100% of the land area in the sub-basin is modelled. The same was true for soil classes and slope ranges distribution in all sub-basins. The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin.

3.8.5 Weather Generator

Lack of full and realistic long period climatic data is the problem in developing countries, particularly, particularly in Ethiopia. Weather generators solve this problem by generating data having the same statistical properties as the actual one (Danuso 2002). SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation (that converted from sunshine hours), relative humidity, and wind speed. The climatic data collected from available meteorological stations in the study area may have too many missing data. As SWAT has built in weather generator called WGEN (Richardson et al., 1984) that is used to fill the gaps, all the missing values filled with a missing data identifier, -99.0.

The weather generator first is independently generating precipitation for the day. Then maximum and minimum temperature, solar radiation and relative humidity are generated based on the presence or absence of rainfall for the day. Finally, wind speed will be generated independently.

For the sake of data generation, weather generator were developed using PCPstata and Dew point temperature calculator (DEW02) (Leirsch, 2003), that downloaded from the SWAT website.

PCPstata calculates the statistical parameter of daily precipitation data used by the weather generator of the SWAT model. DEW program read daily values of relative humidity and maximum and minimum temperature values and calculate monthly average dew point temperature. Other parameters that are not estimated by both (PCPstata and DEW02) were calculated by using Excel built-in Tool-pivot.

Additionally, the maximum half hour rainfall (RAINHHMAX) in the entire period of record for a month has been assumed to be 1/3 of the maximum daily rainfall in a month (Srinivasan, 2013).

3.9. Sensitivity analysis

A sensitivity analysis is used as screening tool for reducing the number of parameters to be adjusted during calibration. The sensitivity of different parameter is impacted by topography, landscape with its characterisation, size of watershed, land use variations and human impacts.

After a thorough pre-processing of the required input (temporal and spatial) for SWAT model, flow simulation was performed for 25 years of recording periods from 1990 - 2014. The first twenty years (1990 – 2009) was used as a model calibration and for the last five years was used as model validation starting from (2010-2014).

The inputs were the observed daily flow data, the simulated flow data and the sensitive parameter in relation to flow with the absolute lower and upper bounded default type of change to be applied method of application was used. After running sensitivity analysis, the sensitive parameters were categorized into four classes based on their mean relative sensitivity from very high to small according to the following Table 3.6.

Table3. 6: Sensitivity classes

Class	Index(I)	Sensitivity
I	$0.00 \leq \lvert I \rvert < 0.05$	Small to negligible
II	$0.05 \leq \lvert I \rvert < 0.20$	Medium
III	$0.20 \leq \lvert I \rvert < 1.00$	High
IV	$\lvert I \rvert \geq 1.00$	Very high

Source: Lenhart et al.(2002).

3.10. Calibration and Validation

Calibration: After parameter sensitivity analysis was undertaken to identify flow parameters which significantly affect the flow hydrograph a trial and error, manual method of parameter adjustments were made several times until the simulated annual water yield fit closer to the actual value. Before going for the determination of the hydrologic components, thorough attempts were made to fine tune the parameters of the model so that the predicted values were in a very close agreement with available measured data.

Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. For this study automatic calibration method were applied. The graphical and statistical approaches ENS, $r^2$and D were used to evaluate the SWAT model performance a number of times until the acceptable values were obtained for surface runoff and base flow independently. The flow calibration procedure made by SWAT developers in Santhi et al. (2001) and Neitsch et al. (2004) were carefully followed. For each calibration run and parameter change, the corresponding model performance statistics R^2, ENS and D were calculated. This procedure was continued until the acceptable calibration statics recommended by SWAT developer for hydrology was achieved. SWAT developers assumed an acceptable calibration for hydrology at a $D \leq 15\%$, $r^2 > 0.6$ and ENS> 0.5 (Santhi et al., 2001; Moriasi et al., 2007).

Validation: Stream flow data of five years from 2010 to 2014were used for validation. The three statistical model performance measures used in calibration procedure were also used in validating daily and monthly stream flow.

3.11. Model performance evaluation

In order to evaluate the performance of SWAT model to determine the quality and reliability of prediction compared to the observed values, the following methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods. The regression coefficient (r^2) describes the proportion of the total variance in the observed data that can be explained by the model.

The closer the value of r^2 to 1, the higher is the agreement between the simulated and the measured flow and is calculated as follow:

$$r^2 = \frac{(\sum[Xi-Xav][Yi-Yav])^2}{\sum[Xi-Xav]^2\sum[Yi-Yav]^2} \quad \text{...(8)}$$

where: Xi is measured value, Xav is average measured value, Yi is simulated value, Yav is average simulated value.

Nash and Sutcliffe simulation efficiency (ENS): indicates the degree of fitness of observed and simulated data and given by the following formula.

$$ENS = 1 - \frac{\sum(Xi - Yi)^2}{\sum(Xav - Yav)^2} \quad \ldots\ldots (9)$$

where: Xi is measured value, Xav is average measured value, Yi is simulated value, Yav is average simulated value.

The value of ENS ranges from 1(best) to negative infinity. The ENS indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all simulations, ENS is 1. If the ENS is between 0 and 1, it indicates deviations between measured and simulated values. If ENS is negative, simulations are very poor, and the average value of output is a better estimate than the model simulation (Nash and Sutcliffe, 1970).

Percentage bias (PBIAS): It is the deviation of simulated data from observed data being evaluated, which is expressed as a percentage. The low magnitude values indicate accurate simulation of the model.

The general performance evaluation for flow on monthly time step is presented in the Table 3.7.

Table3. 7 General Performance ratings for recommended statistics of flow on a monthly time step.

Performance Rating	NSE	R^2
Very Good	$0.7 < NSE < 1.00$	$0.75 < R^2 < 1.00$
Good	$0.6 < NSE < 0.7$	$0.65 < R^2 < 0.75$
Satisfactory	$0.50 < NSE < 0.6$	$0.50 < R^2 < 0.65$
Unsatisfactory	$NSE < 0.50$	$R^2 < 0.50$

Source: Moriasi et al. (2007).

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Watershed Delineations

From a minimum user defined threshold area of 8508.9312 ha, and the watershed is divided into 27 sub-basins, where the total area of delineated watershed is reported by delineator as 3190.66 km^2 as it is outlined in Figure 4.1. Each sub-basin boundary marks the end of reach, the end point of which the accumulation point for all flow from upstream which is then fed into downstream sub-basin and reach. Once the main reach and the longest paths/tributaries are formed, the model uses other physical parameters (soil, land use and land slope) to define HRUs. From the assumed threshold values for HRU delineation, we have found 200 HRUs in 27 sub-basins. Each HRU is composed of land use, soil type and slope parameters.

The areal coverage and percentage of watershed area covered by each land uses, soil types and slope ranges which were used for HRU definition are clearly presented below. A summary of the soil unit and its respective code with areal coverage in the watershed which was used for HRU definition is provided in Table 4.1 and the spatial distribution of each soil unit in the study watershed is also outlined in Figure 4.2.

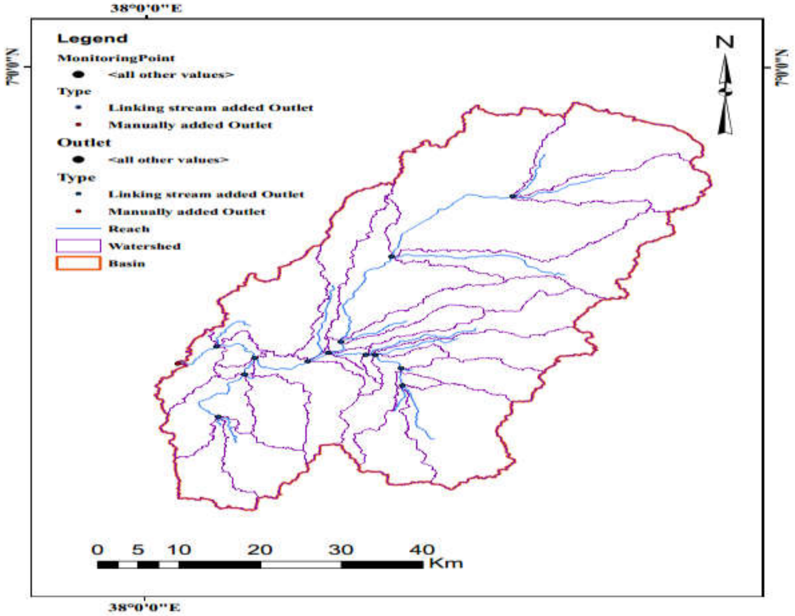


Figure4. 1: Delineated watershed of Gidabo River catchment showing topography and river network.

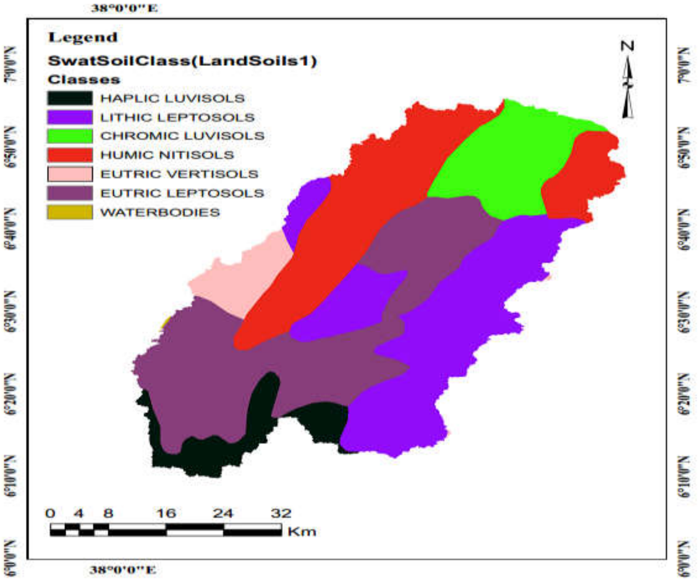


Figure4. 2: Soil map of the study area (source: MoWIE)

Table4. 1: Major soil classes of the study area with their area coverage

SOIL	Area [km2]	% Wat. Area
CHROMIC LUVISOLS	340.89	10.68
EUTRIC LEPTOSOLS	945.45	29.63
EUTRIC VERTISOLS	137.45	4.31
HAPLIC LUVISOLS	210.23	6.59
HUMIC NITISOLS	725.01	22.72
LITHIC LEPTOSOLS	830.65	26.03
WATERBODIES	0.97	0.03
Total	3190.65	100

A summary of the land use and its respective SWAT land use code with areal coverage in the watershed which was used for HRU definition is provided in Table 4.2 and the spatial distribution of each land use type over the study watershed is shown in Figure 4.3.

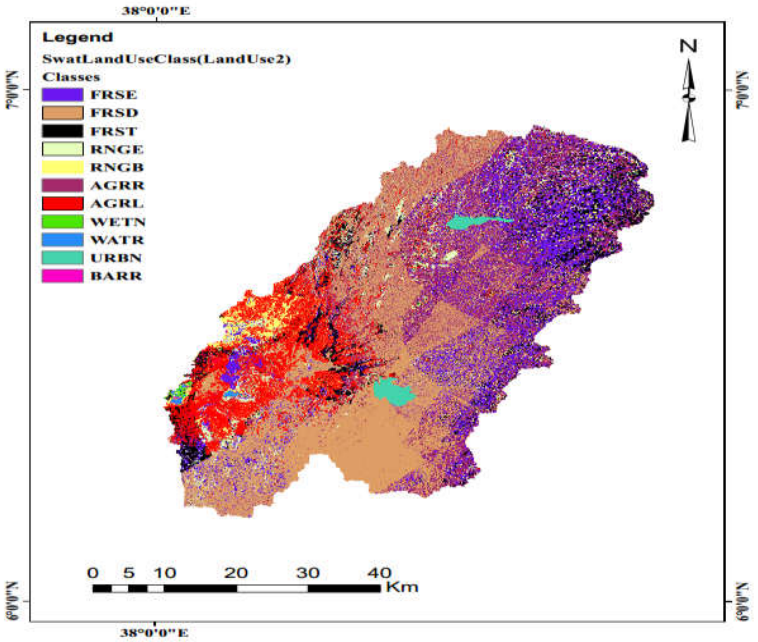


Figure4. 3: Land Use/Cover map of the study area (source: Rift valley Lake Basin, 2013)

Table4. 2: Land use/cover types as redefined by SWAT code with their area coverage.

LANDUSE:	SWAT_ code	Area [km^2]	% Wat. Area
Forest-Evergreen	FRSE	470.87	14.76
Forest-Deciduous	FRSD	108.55	34.02
Forest-Mixed	FRST	294.93	9.24
Range-Grasses	RNGE	197.71	6.20
Range-Brush	RNGB	86.07	2.70
Agricultural Land-Row Crops	AGRR	620.46	19.45
Agricultural Land-Generic	AGRL	385.73	12.09
Wetlands-Non-Forested	WETN	5.78	0.18
Water	WATR	4.95	0.16
Residential (settlement)	URBN	35.08	1.10
Barren (Bare land)	BARR	3.60	0.11
Total		**3190.65**	**100**

Depending on the maximum and standard deviation of land slope in the watershed, this study considered four slope classes, by dividing land slope classes as: class1: 0 to 5%, class2: 5- 12%, class3:12-25% and 25 to 99999%. The maximum value of the slope ranges in SWAT database was assigned by default to be 9999%. Figure 4.4 outlines the spatial distribution of land slope.

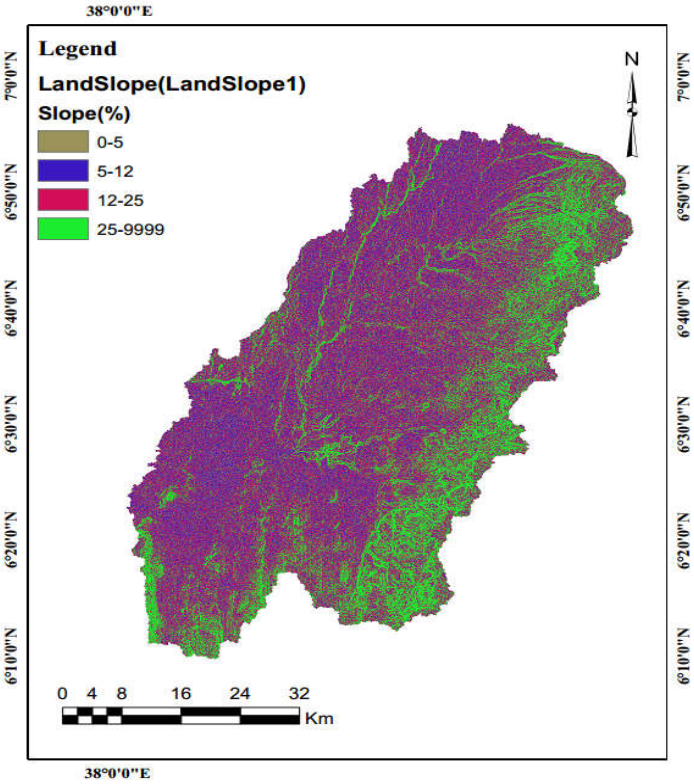


Figure4. 4: Slope classes of the study area

Table4. 3: Slope of the study area with their area coverage.

SLOPE (%)	Area (km^2)	% Wat. Area
0-5	262.45	8.23
5-12	851.04	26.67
12-25	1237.36	38.78
25-9999	839.80	26.32

4.2. Parameters Sensitivity Analysis

Sensitivity analysis was performed on flow parameters of SWAT on monthly time steps with observed data of the Gidabo River. For this analysis, 8 parameters were considered and identified to have significant influence in controlling the stream flow in the watershed. Sensitive flow parameters, relative sensitivity values, parameter ranking and their category were presented in the Table 4.4. A brief description of each hydrologic parameter is listed in the SWAT model user's manual (Neitsch et al., 2004).

Table4. 4. List of Parameters and their ranking values for monthly flow

Parameters		Lower and Upper bound	Ranks
Name	Description		
ALPHA_BF	Base flow alpha factor (days)	-0.002 - 0.2	2
CN2	SCS runoff curve number (%)	- 0.2 to -0.1	1
ESCO	Soil evaporation compensation factor	0 – 2	6
GW_DELAY	Ground water delay (days)	0 - 114 - 66	3
GWQMN	Threshold depth of water inthe shallow aquifer requiredfor return flow (mm)	0.3 – 1	4
SOL_AWC	Soil available water capacity(water/mm soil)	-0.02 – 0.12	7
GW_REVAP	Groundwater "revap" coefficient	-0.13 - 0	5
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	3 - 7	8

The result of the sensitivity analysis indicated that these 8 flow parameters are sensitive to the SWAT model i.e. the hydrological process of the study watershed mainly depends on the action of these parameters. Curve number (CN2), Base flow alpha factor (ALPHA_BF), Ground water delay (GW_DELAY) and threshold depth of water in the shallow aquifer required for return flow (GWQMN) are identified to be highly sensitive parameters and retained rank 1 to 4 respectively. The other parameters such as, Groundwater "revap" coefficient (GW_REVAP), Soil evaporation compensation factor (ESCO), soil available water capacity (SOL_AWC), and Threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN)are identified as slightly important parameters that were retained rank 5 to 8, respectively.

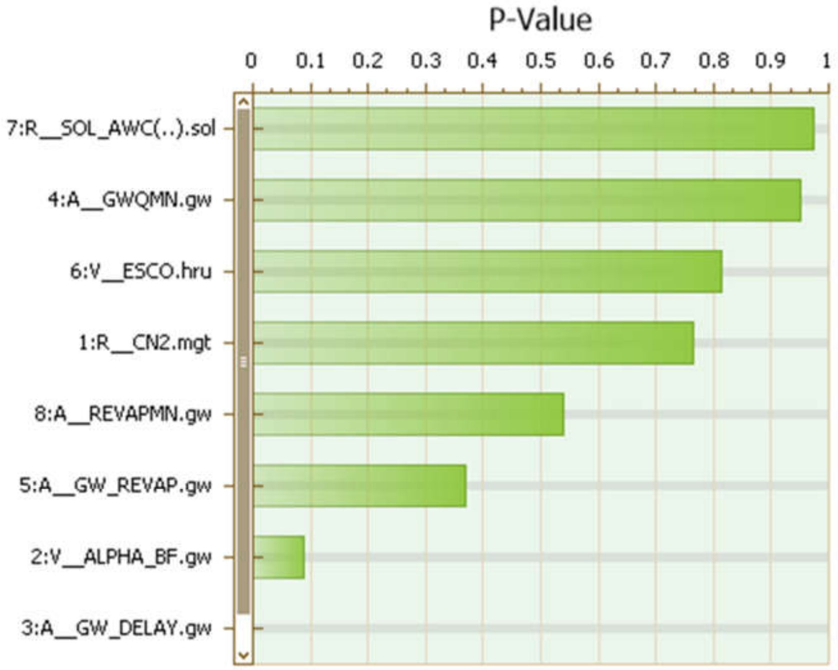


Figure4. 5 Global sensitivity results as per a p-value of significance using SWAT-CUP

4.3. Model Calibration and Validation

The model was run for a period of twenty five years January 1, 1990 to December 31, 2014. The calibration was therefore performed throughout the period of twenty years January 1, 1990 to December 31, 2009 on monthly and daily bases. Model parameters were first calibrated manually which was very time consuming process, followed by automatic calibration using Sufi2.Swat-cup, an auto-calibration tool which is embedded in SWAT 2012. The calibration processes considered 8 flow parameters (Table 4.5) and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The auto-calibration processes significantly improved model efficiency. Table 4.5 illustrates the final calibrated and fitted values. The result from different statistical method of model performance evaluation met the criteria of ENS > 0.5, $r^2 > 0.6$ and PBIAS ≤ ±15%. The statistical results of the model performance for both calibration and validation periods on monthly time steps are summarized in Table 4.6.

Table4. 5. Result of calibrated flow parameters

Parameters		Lower and Upper bound	Fitted value
Name	Description		
ALPHA_BF	Base flow alpha factor (days)	-0.002- 0.036	0.016436
CN2	SCS runoff curve number (%)	-0.16 to -0.12	-0.146524
ESCO	Soil evaporation compensation factor	0.88 – 0.89	0.883657
GW_DELAY	Ground water delay (days)	-20.93 to -6.06	-15.323559
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0.033 – 0.476	0.251396
SOL_AWC	Soil available water capacity (water/mm soil)	-0.903 to-0.679	-0.902762
GW_REVAP	Groundwater "revap" coefficient	-0.046 to -0.024	-0.027078
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	2.800 - 4.001	3.783361

During this step, the model was run for a period of 25 years from 1990 to 2014. The calibration was performed for 20 years from 1990 to 2009. The calibration result for monthly flow is shown in figure 4.5. The result of calibration for monthly flow showed that there is a very good agreement between the measured and simulated average monthly flows with Nash-Sutcliffe simulation efficiency (NSE) of 0.79 and coefficient of determination (R^2) of 0.8 as shown in Table 4.6.

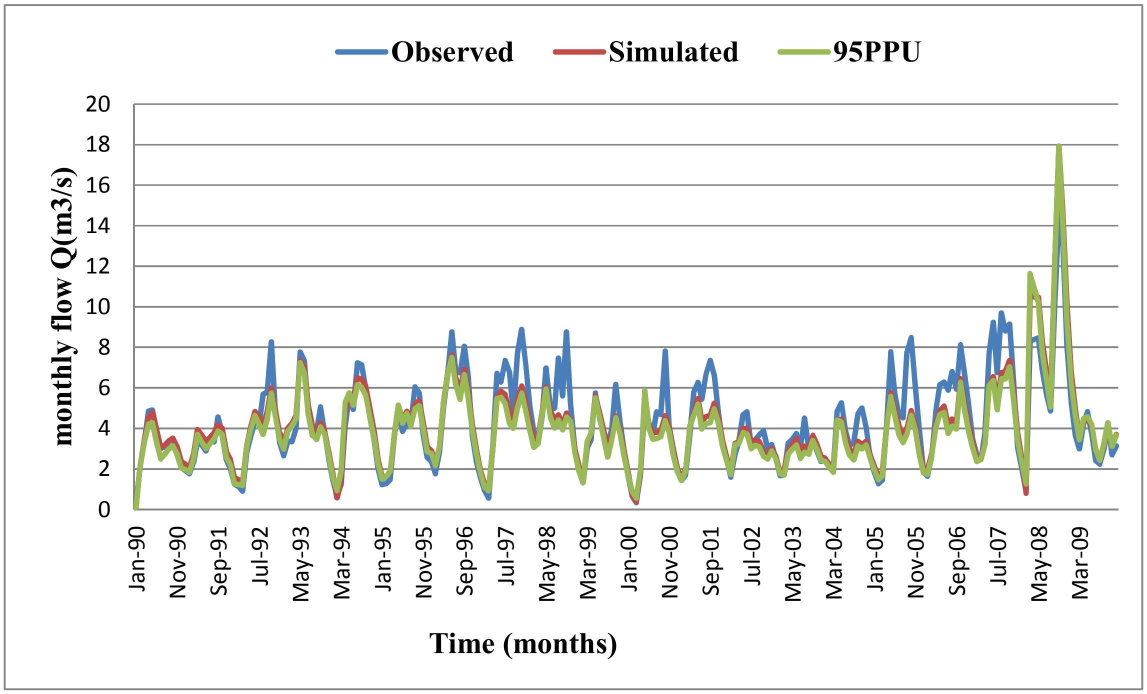


Figure4. 6: The result of calibration for average monthly stream flows (1990 – 2009)

The model validation was also performed for 5 years from 2010 to 2014 without further adjustment of the calibrated parameters. The validation result for monthly flow is shown in figure 4.6. The validation showed a very good agreement between the simulated and measured monthly flow with the NSE value of 0.71 and R^2 of 0.82 as shown in Table 4.6.

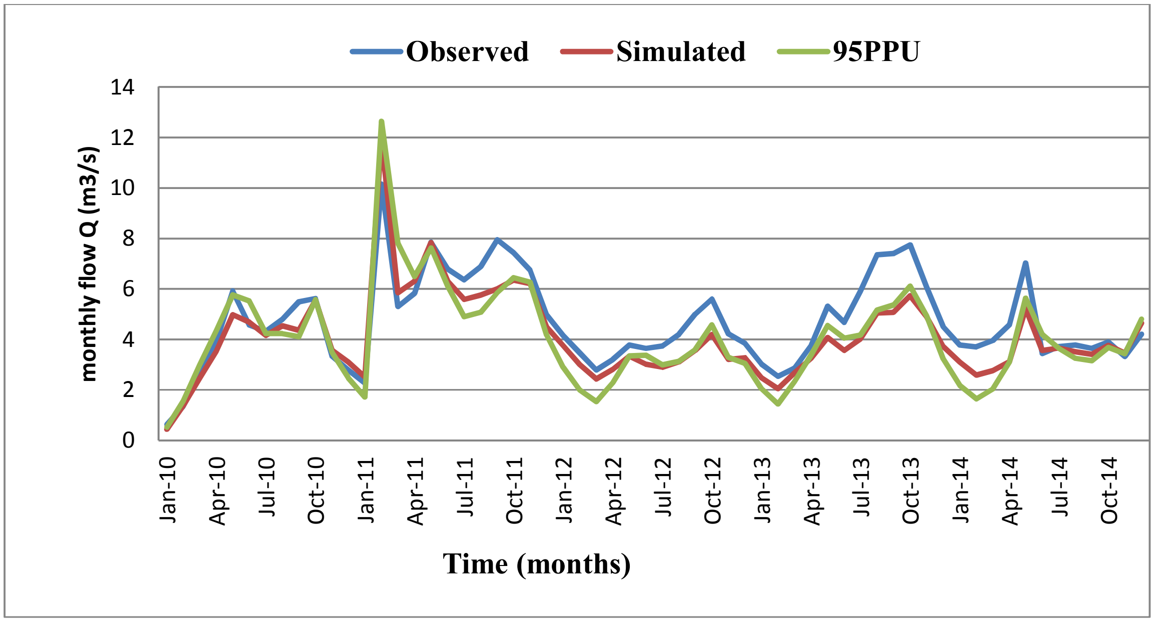


Figure4. 7: The result of validation for average monthly stream flows (2010 -2014)

The measured and simulated average monthly flow for Gidabo watershed was obtained for both calibration and validation. During the calibration period, they were 4.32 and 4.09 m^3/s, respectively. The measured and simulated average monthly flow for the validation period was also 4.69 and 4.09 m^3/s, respectively. These indicate that there is a reasonable agreement between the measured and the simulated values in both calibration and validation periods (Table 4.6).

Table4. 6: Comparison of Measured and simulated monthly flow

Period	Average monthly flow (m^3/s)		NSE	R^2
	Measured	Simulated		
Calibration (1990-2009) Period	4.32	4.09	0.79	0.80
Validation (2010 - 2014) Period	4.69	4.09	0.71	0.82

As can be indicated in Table 4.6, the model performance values for the calibration and validation of the flow simulations are very good. This indicates that the model adequately captured the physical processes involved in the generation of stream flow in the watershed. Hence, the model simulations can be used for various water resource management and development aspects.

The following figures showed that the values of the scatter plots of the measured and simulated monthly flows data for the calibration and validation periods. There is a fire linear correlation between the two datasets (measured and simulated).

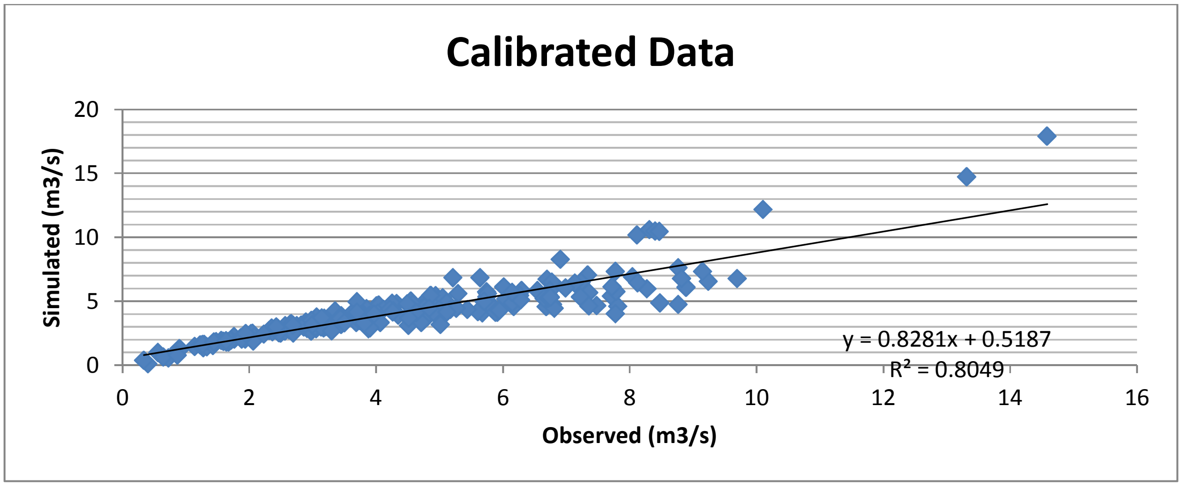


Figure4. 8: Scatter plots of the calibration periods.

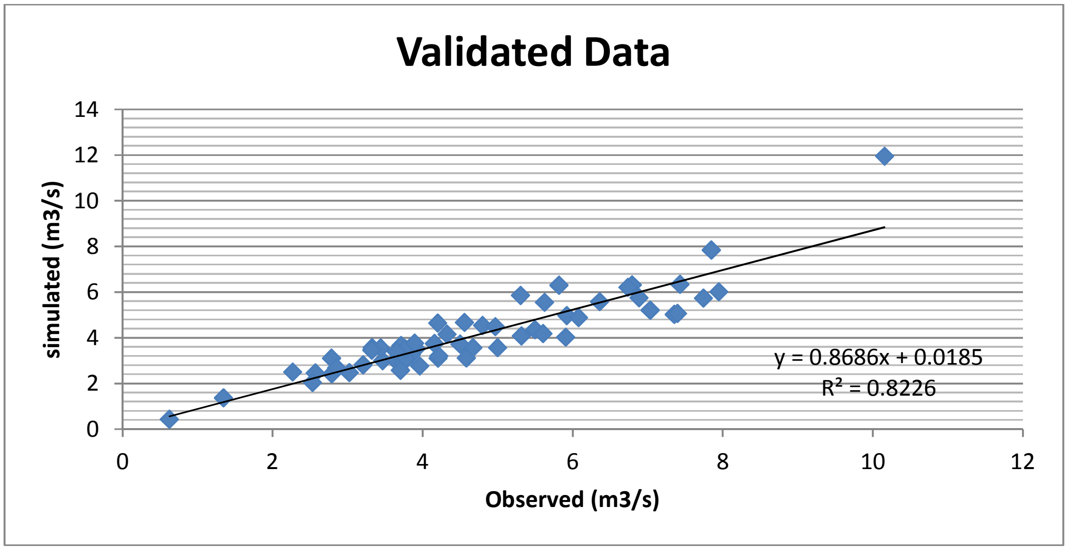


Figure4. 9: Scatter plots of the validation periods.

In general, the Model performance assessment indicated that there are a good correlation and agreement between the monthly measured and simulated flows.

4.4. Monthly and Average Annual Water Balance Components of the Watershed

The SWAT model estimated other important water balance components in addition to the monthly discharge of the watershed. Water yield is one of the important parameters estimated by the model for efficient water management and planning of the study area. The contribution made by each sub-watershed in the watershed area to the total water yield during the simulation period was examined using the calibrated model.

To deal with water management issues, it is perfect to analyse and quantify the diverse components of hydrological processes occurring within the study area. The SWAT model estimated other pertinent water balance components in addition to the monthly flow or discharge. Reference Sathian and Syamala (2009), stated that the most imperative components of the water balance of a watershed are; precipitation, surface runoff, lateral flow, and ET.

The annual average basin values were presented in the Table below. The average annual precipitation was 1435.58 mm. This precipitation apportioned to different water balance components in which water yield has accounted high followed by potential evapotranspiration (690.73mm) and Percolation out of the soil (874.15 mm). Surface runoff and deep aquifer recharge contributed less to the flow.

Table4. 7: Average Annual water balance components of the basin

Water Balance Components	Average annual values(mm)
Precipitation	1435.58
Surface runoff	62.20
Lateral flow through soil	271.31
Groundwater (shallow aquifer)	813.24
Groundwater (deep aquifer)	42.98
Deep aquifer recharge	43.59
Total water yield	1189.73
Percolation out of soil	874.15
Actual Evapotranspiration	228.40
Potential evapotranspiration	690.73

Average annual water balance simulated for a base period of 1990 through 2014 in sub-basins and its variability across the watershed is as displayed in the figure below.

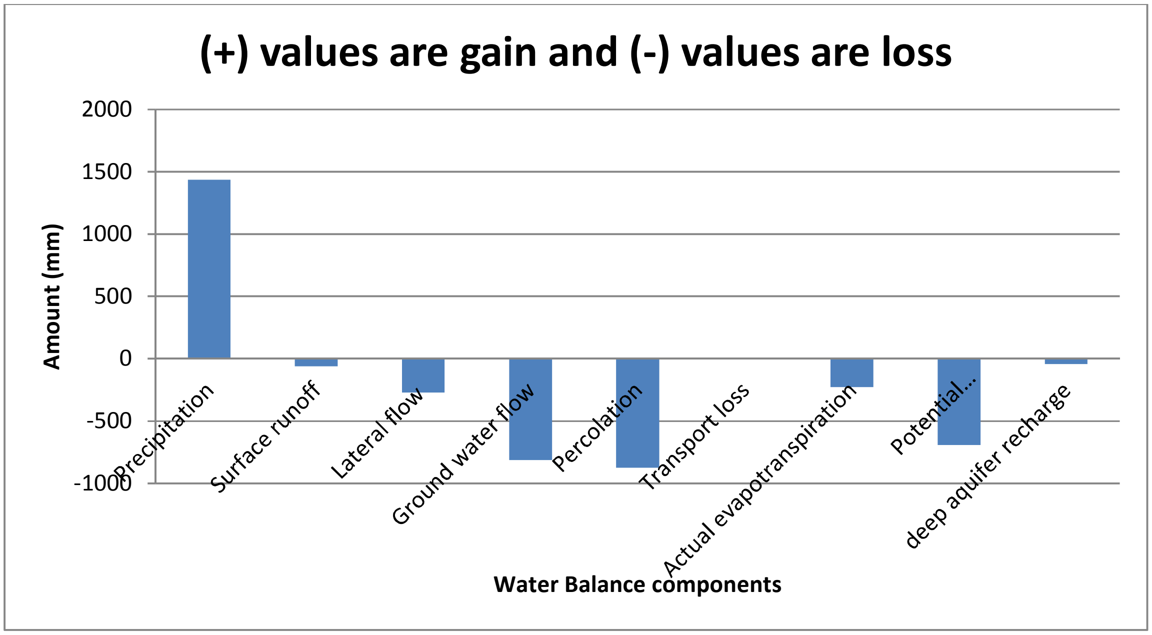


Figure4. 10: Average annual water balances for Gidabo watershed

The monthly basin values were presented in Table 4.8. The hydrological parameters such as water yield, surface flow, groundwater flow indicated a good relationship with precipitation. Generally, water yield was more from May to November in a year and relatively low at February, January, March and December in a year.

The model simulated surface runoff using curve number technique and lateral flow through soil by storage routing technique. Whenever there is rainfall, surface runoff and lateral flow have contributed to the stream flow. The maximum amounts of surface runoff simulated were 9.38mm and 10.18 mm respectively in the months of September and October that coincided with the highest amount of rainfall recorded during the months.

Table4. 8: Average Monthly water balances of the Basin.

MONTHS	RAIN	SURF Q	LAT Q	WATER YIELD	ET	PET
	(MM)	(MM)	(MM)	(MM)	(MM)	(MM)
1	38.11	0.86	6.58	44.73	9.72	59.80
2	58.53	3.12	11.00	39.25	10.75	60.01
3	122.09	4.94	22.50	61.52	22.01	72.92
4	186.87	7.55	34.73	96.81	27.90	63.75
5	201.88	8.89	39.93	138.60	27.66	58.00
6	112.63	3.50	22.02	124.97	23.04	55.05
7	114.22	4.37	20.44	112.03	20.89	53.20
8	136.13	6.10	24.89	109.33	21.70	55.16
9	185.94	9.38	34.70	124.97	22.63	54.35
10	179.48	10.18	34.80	147.73	20.41	55.31
11	64.65	2.72	13.29	113.05	12.03	49.36
12	35.05	0.56	6.35	76.40	9.58	53.30
Total	**1435.58**	**62.17**	**271.23**	**1189.39**	**228.32**	**690.21**
Average	**119.63**	**5.18**	**22.60**	**99.12**	**19.03**	**57.52**

4.5. Assessment of Spatial and Temporal Distribution of Available Surface Water

Surface water availability has been identified by spatial and temporal forms that resulted from the SWAT simulated outputs of stream flow in each sub-basin of the watershed. The mean minimum monthly surface water flow results of the watershed indicated that 2.16m^3/s on December to a maximum of 12.54m^3/s on October.

Table4. 9: Average monthly simulated stream flow results in each sub-watershed (m^3/s)

Sub-basin	**Area (km^2)**	**Months**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	212.62	0.58	0.78	0.78	0.84	0.70	0.31	0.58	0.72	1.29	0.82	0.41	0.37
2	145.76	0.19	0.31	0.36	0.34	0.28	0.16	0.16	0.28	0.29	0.48	0.06	0.03
3	569.41	2.36	2.53	3.07	2.29	1.73	0.89	1.00	1.64	1.75	2.84	0.38	0.18
4	197.47	0.47	0.44	0.57	0.47	0.60	0.25	0.44	0.56	0.96	0.75	0.19	0.04
5	204.96	0.48	0.66	0.94	0.76	0.95	0.39	0.56	0.62	0.97	0.78	0.19	0.03
6	106.24	0.05	0.08	0.23	0.25	0.26	0.11	0.21	0.28	0.50	0.39	0.10	0.10
7	187.49	0.71	2.30	2.87	2.88	3.31	1.83	1.66	1.98	2.83	3.06	1.68	0.92
8	52.46	0.03	0.09	0.05	0.06	0.07	0.02	0.03	0.06	0.10	0.13	0.05	0.01
9	110.86	0.04	0.16	0.24	0.19	0.24	0.10	0.20	0.25	0.45	0.35	0.09	0.02
10	121.33	0.18	0.12	0.28	0.16	0.21	0.09	0.17	0.22	0.40	0.31	0.08	0.02
11	7.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
12	9.74	0.00	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.01	0.00
13	26.66	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	121.99	0.10	0.23	0.41	0.91	0.92	0.39	0.83	0.54	0.93	0.78	0.40	0.32
15	18.58	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.01	0.00
16	62.42	0.02	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
17	88.00	0.05	0.04	0.07	0.07	0.06	0.02	0.02	0.02	0.03	0.05	0.02	0.00
18	129.95	0.12	0.11	0.24	0.27	0.20	0.06	0.06	0.08	0.13	0.18	0.06	0.01
19	87.57	0.03	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	10.82	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	96.26	0.03	0.07	0.10	0.06	0.08	0.02	0.02	0.03	0.04	0.07	0.03	0.00
22	13.03	0.03	0.13	0.18	0.20	0.21	0.09	0.11	0.11	0.17	0.19	0.10	0.05
23	95.42	0.04	0.10	0.14	0.13	0.18	0.04	0.05	0.07	0.09	0.14	0.05	0.00
24	110.98	0.15	0.02	0.19	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00
25	87.32	0.03	0.14	0.20	0.19	0.25	0.06	0.07	0.09	0.13	0.20	0.06	0.01
26	215.29	0.62	0.91	0.81	0.63	0.44	0.14	0.61	0.34	0.58	0.73	0.58	0.03
27	100.10	0.08	0.25	0.30	0.22	0.24	0.06	0.22	0.09	0.13	0.20	0.22	0.00
Total	**3190.66**	**6.42**	**9.59**	**12.22**	**11.09**	**10.97**	**5.06**	**7.01**	**8.02**	**11.82**	**12.54**	**4.82**	**2.16**

4.6. Agricultural Water Demand Analysis.

4.6.1. Gross irrigation water requirement

Gross irrigation requirements of each selected crops (Tomato and Maize) at identified potential irrigable lands were estimated using CROPWAT8.0 software. Each crop adopted in the area various in a real coverage, 30% of Potato and 70% of Wheat of the total irrigable sites. Table 4.11, describes monthly gross irrigation water requirements of Potato and Wheat resulted from monthly water demands of the full growth stage of Potato and Wheat that should be abstracted from the local cropping period.

Table4. 10: Monthly requirements of crop types resulted from CROPWAT8.0

	monthly requirements of crop types	
Months	Wheat (mm/day)	Potato (mm/day)
Jan	3.87	4.33
Feb	9.00	8.06
Mar	10.86	10.92
Apr	10.19	9.64
May	5.62	2.24
Jun	0.00	0.00
Jul	0.00	0.00
Aug	0.00	0.00
Sep	0.00	0.00
Oct	0.00	0.00
Nov	0.00	0.00
Dec	0.00	0.00

Based on master plan studies of RVLB, the planned irrigable land of Gidabo catchment was 9215ha. During this study, to identify the irrigation suitability land they considered soil and slope as well as they allocate the available water to other sectors (Halcrow Group Limited and GIRD, 2009). As it is indicated in the Table 4.11, monthly gross irrigation water requirements of Potato and Wheat resulted from monthly water demands of the full growth stage of the crop types in respect of their percentage of coverage.

Table4. 11: Gross irrigation requirements of the selected crops in (m^3/s)

	Monthly requirements of crop types		Gross Irrigation Requirements (m3/s)		
Months	Wheat (mm/day)	Potato (mm/day)	Wheat	Potato	Total (m3/s)
Jan	3.87	4.33	2.89	1.39	4.27
Feb	9.00	8.06	6.72	2.58	9.30
Mar	10.86	10.92	8.11	3.49	11.60
Apr	10.19	9.64	7.61	3.08	10.69
May	5.62	2.24	4.20	0.72	4.91
Jun	0.00	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00

4.6.2 Irrigation Potential of River Catchments

Surface irrigation potential of the river catchments was obtained by comparing irrigation requirements of the identified suitable area and the available mean monthly flows in the river catchments based on the methods suggested by (FAO, 1997). Table 4.12, represents gross irrigation requirements of the two crops commonly grown in catchment area (potato and wheat) and the available mean monthly flows obtained from SWAT simulation outputs in watersheds. The analysis result revealed that the mean monthly flow of the watershed was more than the corresponding gross monthly irrigation requirements of crops throughout the crops growing period in the area. From the Table 4.12, the minimum available flow in the month of January, February, March, April and May in watershed is 6.42, 9.59, 12.22, 11.09 and 10.97 m^3/s respectively whereas the water requirement of the two crops 4.27, 9.30, 11.60, 10.69 m^3/s and 4.91 m^3/s respectively giving a critical command area (that can be reliably irrigated using the available flow) of 9215ha.

Therefore, the irrigation potential of the river catchments in the study area is obtained.

Table4. 12: Comparison of GIWR and available stream flows at irrigable area

months	GIR (m3/s)	Flow (m3/s)
Jan	4.27	6.42
Feb	9.30	9.59
Mar	11.60	12.22
Apr	10.69	11.09
May	4.91	10.97
Jun	0.00	5.06
Jul	0.00	7.01
Aug	0.00	8.02
Sep	0.00	11.82
Oct	0.00	12.54
Nov	0.00	4.82
Dec	0.00	2.16

Hence, the total irrigation potential of the study area is found to be 9215ha which is potentially suitable area that could be irrigated consistently with the available runoff from the river systems. As it is indicated in the Table 4.12, the available water is much enough with the corresponding crop water requirement for the cropping months.

Based on this irrigation potential of the study area which is obtained from critical command area the gross irrigation water requirements of the crops (Wheat and Potato) was calculated with respective of their percentage of coverage among the potentially suitable area (70%, for Wheat and 30%, for Potato).

Table4. 13: Summarized monthly flow available and gross irrigation water requirement of potential sites

	monthly requirements of crop types		**Gross Irrigation Requirements (m3/s)**			
months	**wheat (mm/day)**	**potato (mm/day)**	**wheat**	**potato**	**total (m3/s)**	**Flow (m3/s)**
Jan	3.87	4.33	2.89	1.39	**4.27**	**6.42**
Feb	9.00	8.06	6.72	2.58	**9.30**	**9.59**
Mar	10.86	10.92	8.11	3.49	**11.60**	**12.22**
Apr	10.19	9.64	7.61	3.08	**10.69**	**11.09**
May	5.62	2.24	4.20	0.72	**4.91**	**10.97**
Jun	0.00	0.00	0.00	0.00	**0.00**	**5.06**
Jul	0.00	0.00	0.00	0.00	**0.00**	**7.01**
Aug	0.00	0.00	0.00	0.00	**0.00**	**8.02**
Sep	0.00	0.00	0.00	0.00	**0.00**	**11.82**
Oct	0.00	0.00	0.00	0.00	**0.00**	**12.54**
Nov	0.00	0.00	0.00	0.00	**0.00**	**4.82**
Dec	0.00	0.00	0.00	0.00	**0.00**	**2.16**

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

Understandings on hydrological processes and develop suitable models for a watershed is the most important aspect in water resources development and management programmes. Watershed based hydrologic simulation models are likely to be used for the assessment of the quantity and quality of water. The performance and applicability of SWAT model was successfully evaluated through sensitivity analysis, model calibration and validation.

According to the result obtained from sensitivity analysis with measured discharge, subsurface flow parameters were found to be more sensitive to the stream flow of the watershed. Consequently, base flow was an important component of the hydrology of the study watershed, signifying the watershed is rich in ground water as a result of good recharge capacity. The stream flow simulation performance of the model for calibration and validation periods was evaluated using graphical and statistical methods. Model efficiency criteria were fulfilled the requirements of r2> 0.6and ENS > 0.5 for both monthly flow calibration and validation periods. Accordingly, SWAT model was found to produce a reliable estimate of monthly runoff for Gidabo watershed. However, the model was weaker for the simulation of daily stream flow in both calibration and validation periods, particularly, the daily peak events were underestimated and low flows were overestimated. Overall, the simulated and measured discharge followed similar patterns and trend, thus, SWAT model can be used for hydrologic simulation of Rift valley watershed with similar characteristics to Gidabo river watershed. However, for a more accurate modelling of hydrology, a large effort will be required to improve the quality of available input data. Water balance components of the watershed were estimated in other forms from stream flow as to average monthly and annual forms in which water yield, ground water (shallow aquifer), potential evapotranspiration and Percolation out of the soil has accounted high. Surface runoff and deep aquifer recharge contributed less to the flow. The availability of surface water was identified throughout the delineated watershed by spatial and temporal forms that resulted from the SWAT simulated outputs of stream flow. Gross irrigation requirements of each selected crops (Tomato and Maize) were estimated using CROPWAT8.0 software. As it was indicated at the result part Table 4.12, the available water is much enough with the corresponding crop water requirement for the cropping months following the potential irrigable area.

5.2. Recommendations

- The SWAT model performed well in simulating monthly flow of the Gidabo watershed. Therefore, the calibrated parameter values can be considered for further hydrologic simulation of the watershed and the model can be taken as a potential tool for simulation of the hydrology of unguaged watershed in Rift valley areas of Ethiopia which behave hydro-meteorologically similar with Gidabo watershed.
- Proper recording and handling of time series data should be exercised for a better prediction efficiency of the watershed modelling. A hydrologic model is highly reliant on the input datasets so that, due attention need to be paid for the measurement and computation of the governing input such as meteorological and hydrological data otherwise, calibration and validation of SWAT model would be difficult.
- The daily flow calibration and validation result were below acceptable model efficiency criteria. If additional weather stations in the watershed are used in connection with a finer resolution in spatial inputs, it is possible to improve and bring the values of calibration and validation to acceptable ranges.
- Future studies on Gidabo watershed modelling should address the issues related to water quality including sedimentation, nutrients, and evaluate best management practices to address different water quality issues in the watershed, and baseline and future climate change impacts on water recourses availability.
- Similarly, accurate sampling and measurement of sedimentation and other water quality parameters have to be addressed by responsible bodies together with a better weather and flow datasets.
- It is only recommended to use the output of model simulation after proper model calibration and validation using measured datasets and subsequently, this hydrologic simulation model can be used to formulate strategies for soil and water conservation in a watershed.
- To develop sound and reliable irrigable land for sustainable irrigation in the watershed ground water potentials should be considered.
- In addition, some other factors such as: distance from the market/town, environmental, and socio-economic issues should also be taken in to account for further irrigable land assessment

REFERENCES

A.A. Shawul. et al, (2013). Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, south eastern Ethiopia. Hydrology and Earth System Sciences Discussion, HESSD 10, 13955 – 13978.

Abbaspour, K.C., 2011. User Manual for SWAT-CUP: SWAT Calibration and Uncertainty Analysis Programs. Eawag: Swiss Fed. Inst.of Aquat.Sci. and Technol., Duebendorf, Switzerland, pp.103.

Abbaspour, K.C., Johnson, C.A., van Genuchten, M.T., 2004. Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone J. 3, 1340–1352.

Abbaspour, K.C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., Srinivasan, R. 2007. Modelling of hydrology and water quality in the pre-alpine/alpine Thurwatershed using SWAT. J. Hydrol. 333, 413–430.

Ashenafi Tedla, 2009. Impact assessment of land use / land cover changes on Shaya river flow using SWAT (case study of Shaya watershed, in Bale). M.Sc. Thesis. Arbaminch University, Ethiopia. 130p.

Arnold, J. G., 1993.A comprehensive surface-ground water flow model. J. Hydrol. 142: 47-69.

Arnold, J. G., P. M. Allen, R. Muttiah and G.Bernhardt, 1995. Automated base flow separation and recession analysis techniques. Ground Water 33(6): 1010-1018.

Arnold,J.G., R. Srinivasan, R. R. Muttiah and J. R. Williams, 1998. Large area hydrologic modelling and assessment part I: model development. J. Am. Water Resour. Assoc.34 (1): 73–89.

Arnold,J. G. and P. M. Allen, 1999. Automated methods for estimating base flow and ground water recharge from stream flow records. J. Am. Water Resour. Assoc. 35(2): 411-424.

Ayivi, F., & Jha, M. K 2018. Estimation of water balance and water yield in the Reedy Fork Buffalo Creek Watershed in North Carolina using SWAT. International Soil and Water Conservation Research, https://doi.org/10.1016/j.iswcr.2018.03.007.

Balint, Z. et al, (2011): Somali Water and Land Resources, FAO-SWALIM Nairobi, Kenya.

Ben Asher,J., G. Oron and B. J. Button, 1988.Estimation of runoff volume for agriculture in arid lands.Jacob Blaustein Institute for Desert Research, Ben Gurion University of the Negev.

Biniam Biruk, 2009. SWAT to Identify watershed management options: (Anjeni Watershed, Blue Nile Basin, Ethiopia). MSc. Thesis Presented to the Graduate School of Cornell University. 121p.

Birhanu Zemedim, P.M. Ndomba andF.W.Mtalo, 2007.Application of SWAT model for mountainous catchment. Catchment and Lake Research.LARS 2007: 182-187.

Brooks,K. N. P. F. Folliott, H. M.Gregersen and L. F.De Bano, 1997. Hydrology and the Management of Watersheds (2nded).Iowa State University Press.

Bronstert,A.D. Niehoff and G. Burger, 2002. Effects of climate and LULC change on storm runoff generation: Present Knowledge and Modeling Capabilities Hydrol. Process, 16: 509–529.

Carey,B. W. G. J. Leach and B.Venz, 2004. Soil erosion in Queensland cropping lands a historicalperspective and new challenges. Proceedings 13thInternational Soil Conservation Organisation Conference, Brisbane.

Coffey; M. E., S. R. Workman, J. L.Taraba and A.W. Fogle, 2004. Statistical procedures for evaluating daily and monthly hydrologic model predictions. Transactions of the ASAE 47(1): 59-68.

Danuso, F.2002. Stochastic model for weather data generation. Italian Journal of Agronomy 6(1):57-71.

Dilnesaw Alamirew, 2006. Modeling of hydrology and soil erosion of Upper Awash River Basin, PhD Dissertation. University of Bonn, Germany. 236p.

Eckhartd, K. and J. G. Arnold, 2001. Automatic calibration of a distributed catchment model. J. Hydrol., 251: 103-109.

Eyob, Yehayis, 2010. Predicting Runoff and Sediment Yield using SWAT Model for Ija Galma Waqo Spate Irrigation Project. M.Sc. Thesis. Haramaya University, Ethiopia. 94p.

FAO/UNESCO-ISWC, 1998. The World Reference Base for Soil Resources. Rome, Italy.

Farm-Africa-SOS Sahel Ethiopia, 2007. Participatory Natural Resource Management Programme and Oromia Bureau of Agriculture and Rural Development, Six Months Report.

Francos, A., F. J. Elorza, F. Bouraoui, G. Bidoglio and L. Galbiati, 2003. Sensitivity analysis of distributed environmental simulation models: Understanding the model behaviour in hydrological studies at the catchment scale. Real. Eng. Syst. Safe. 79(2): 205-218.

Gassman,W. P, M. R. Reyes, C. H. Green and J. G. Arnold, 2005. SWAT peer–reviewed literature: A review, Proceedings of the 3rd International SWAT conference, Zurich.

Gassman, W. P., M. R. Reyes, C. H. Green and J. G. Arnold, 2007. The Soil and Water Assessment Tool: Historical development, Applications, and future Research Direction. Transactions of the ASABE50(4): 1211-1250.

Global Water Partnership (GWP), Integrated Water Resources Management—(TAC background paper no. 4); GWP: Stockholm, Sweden, 2000.

Green.W. H. and G. A. Ampt, 1911. Studies on soil physics,1. The flow of air and water through soils. Journal of Agricultural Sciences4:11-24.

Halcrow, 2008. Rift Valley Lakes Integrated Natural Resources Development Master Plan Ethiopian Valleys Development Studies Authorities, Ministry of Water Resources, Addis Ababa, Ethiopia.

Hamby, D. M., 1994. A review of techniques for parameter sensitivity analysis of environmental models. Environmental Monitoring and Assessment32: 135–154.

Hargreaves, G. L., G. H. Hargreaves and J. P. Riley, 1985. Agricultural benefits for Senegal River basin. J. Irrig. and Drain.Engr.111(2): 113-124.

Hargreaves, G. H and G. P. Merkley, 2004. Irrigation Fundamentals. Water Resources Publications, LLC.

Holvoet, K., A. Van Griensven, P. Seuntjens and P. A. Vanrolleghem, 2005. Sensitivity analysis for hydrology and pesticide supply towardsthe river in SWAT. Phys. Chem. Earth30(8-10): 518-526.

McCornick, P. G., A. B. Kamara and Girma Tadesse. (eds), 2003. Integrated water and land management research and capacity building priorities for Ethiopia. Proceedings of aMoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia.

McCuen, R. H., 1989. Hydrologic Analysis and Design. Prentice Hall. pp. 355-360.

Monteith, J. L., 1965. Evaporation and the environment. pp. 205-234. In the state and movement of water in living organisims, XIXth Symposium. Soc. For Exp. Biol., Swansea, Cambridge University Press.

MoWE, 2007. Genale-Dawa River Basin Integrated Resources Development Master plan Study, Sector Reports.

Nash, J. E. and J. V. Sutcliff, 1970. River flow forecasting through conceptual models, part I- a discussion of principles. Journal of Hydrology, 10:282-290.

Neitsch, S. I., J. G. Arnold, J. R. Kinrv and J. R. Williams, 2005. Soil and Water Assessment Tool, Theoretical Documentation: Version 2005. Temple, TX. USDA Agricultural Research Service Texas A and M Black land Research Center.

Nicks, A. D, 1974. Stochastic generation of the occurrence, pattern and location maximum amount of daily rainfall. p. 154-171. In Proc. Symp. Statistical Hydrology, Tucson, AZ. Aug.-Sept. 1971. USDA Misc. Publ. 1275. U.S. Gov. Print.Office Washington, DC.

Priestley, C. H. and R. J. Taylor, 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Mon Weather. Rev. 100: 81-92.

Refsgaard, J. C. and B. Storm, 1996. Construction, calibration and validation of hydrological models, Distributed Hydrological Modelling (eds. M.B.Abbott and J.C. Refsgaard), Kluwer Academic Publishers, pp. 41-54.

Sanjay, K. T. Jaivir and S. Vishal, 2010. Simulation of runoff and sediment yield for a Himalayan watershed using SWAT model.Journal of Water Resource and Protection2(3): 267-281

Santhi, C., J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan and L. M. Hauck, 2001. Validation of the SWAT model on a large river basinwith point and nonpoint sources. J. Am. Water Resour. Assoc.37(5): 1169-1188.

Sathian, K. K. and P. Symala, 2009. Application of GIS integrated SWAT model for basin level water balance. Indian Journal of Soil Conservation 37(2):100-105.

Setegn Shimelis, 2010. Modeling hydrological and hydrodynamic processes in Lake Tana Basin, Ethiopia, KTH. TRITA-LWR PhD Thesis 1057.

Seibert, J. and J. J. McDonnell, 2010. Land-cover impacts on streamflow: a change-detection modelling approach that incorporates parameter uncertainty. Hydrol. Sci. J. 55(3): 316–332.

Silveira, L., F. Charbonnier and J. L. Genta, 2000. The antecedent soil moisture condition of the curve number procedure. J. Hydro. Sci.45(1): 3.

Sharpley, A. N. and J. R.Williams, 1990. EPIC-Erosion Productivity Impact Calculator, 1. Model documentation. U.S. Department of Agriculture, Agricultural Research Service, Tech. Bull. 1768.

Smedema, L. K. and D. W. Rycroft, 1983. Land drainage-planning and design of agricultural drainage systems, Cornell University Press, Ithica,N.Y.

Spruill, C. A., S. R. Workman and J. L. Taraba, 2000. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. Transactions of the ASAE43(6): 1431-1439.

The Federal Democratic Republic of Ethiopia Ministry of Water Resources Halcrow Group Limited Generation Integrated Rural Development (GIRD, 2009). Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project. Volume2.

USDA Soil Conservation Service (SCS), 1972. National Engineering Handbook Section 4 Hydrology, Chapters 4-10.

Van Griensven, A., A. Francos and W. Bauwens, 2002. Sensitivity analysis and auto calibration of an integral dynamic model for river water quality. Water Sci. Technol. 45: 325-332.

Van Griensven, A., 2005. Sensitivity, auto-calibration, uncertainty and model evaluation in SWAT 2005. UNESCO-IHE. 48p.

White, K. and R. A. Sloto, 1990. Base flow frequency characteristics of selected Pennsylvanian stream U.S. Geologic Survey Water Resources Investigation Report 90-4160. 66p.

White, K. and I. Chaubey, 2005. Sensitivity analysis, calibration and validations for a multisite and multi-variable SWAT model. J. Am. Water Resour. Assoc.41(5):1077-1089.

White, E. D, 2009. Development and application of a physically based landscape water balance in the SWAT model. MSc. Thesis Presented to the Graduate School of Cornell University. 70p.

Williams, J. R., 1995. The EPIC model. P. 909-1000.In V. P. Singh (ed). Computer models of watershed hydrology. Water resources Publications, Highlands Ranch, CO.

APPENDICES

Appendix I: Weather Generator Statistic and Probability Value of Weather Station

Table1. Statistical values for Dilla weather station (Synoptic station) (1990-2014)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
TMPMX	27.2	27.3	28.4	29.0	27.5	27.5	25.2	24.4	26.0	26.7	26.9	27.9
TMPMN	13.0	12.6	12.4	11.9	11.9	13.4	14.3	19.2	13.2	12.2	11.7	13.4
TMPSTDMX	1.6	5.3	2.5	2.2	1.6	1.5	1.8	1.6	1.4	1.7	1.5	1.4
TMPSTDMN	2.9	3.7	2.4	1.7	1.8	1.7	1.8	1.7	1.7	2.0	2.4	3.2
PCPMM	149.9	182.5	127.9	74.1	59.1	75.9	103.3	130.9	182.7	180.3	95.0	121.5
PCPSTD	8.5	9.1	7.3	5.6	5.4	6.7	8.0	8.6	9.4	8.8	6.4	7.3
PCPSKW	2.7	1.9	2.5	3.6	5.7	3.4	2.9	3.0	2.7	2.4	3.3	2.8
PR-W1	0.5	0.5	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.4	0.4
PR-W2	0.6	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6
PCPD	18.1	20.1	17.4	12.3	9.3	9.7	11.0	14.9	19.5	20.3	15.0	17.0
RAINHHMX	8.9	13.1	16.0	22.9	22.7	18.5	23.3	23.8	13.8	19.4	23.7	12.0
SOLARAV	7.3	10.2	10.2	7.3	0.2	6.4	8.7	7.0	7.3	7.6	7.0	7.7
DEWPT	6.1	5.8	6.5	5.7	4.0	5.2	3.3	5.6	6.3	7.2	7.0	7.9
WNDAV	0.5	0.7	0.7	0.5	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4

Where:-

TMPMX: Average or mean daily maximum air temperature for month (ºC).

TMPMN: Average or mean daily minimum air temperature for month (ºC).

TMPSTDMX: Standard deviation for daily maximum air temperature in month (ºC).

TMPSTDMN: Standard deviation for daily minimum air temperature in month (ºC).

PCPMM: Average or mean total monthly precipitation (mm H2O).

PCPSTD: Standard deviation for daily precipitation in month (mm H2O/day).

PCPSKW: Skew coefficient for daily precipitation in month.

PR_W1: Probability of a wet day following a dry day in the month.

PR_W2: Probability of a wet day following a wet day in the month.

PCPD: Average number of days of precipitation in month.

RAINHHMX: Maximum 0.5 hour rainfall in entire period of record for month (mm H2O).

SOLARAV: Average daily solar radiation for month (MJ/m/day)

DEWPT: Average daily dew point temperature in month (ºC).WNDAV: Average daily wind speed in month (m/s).

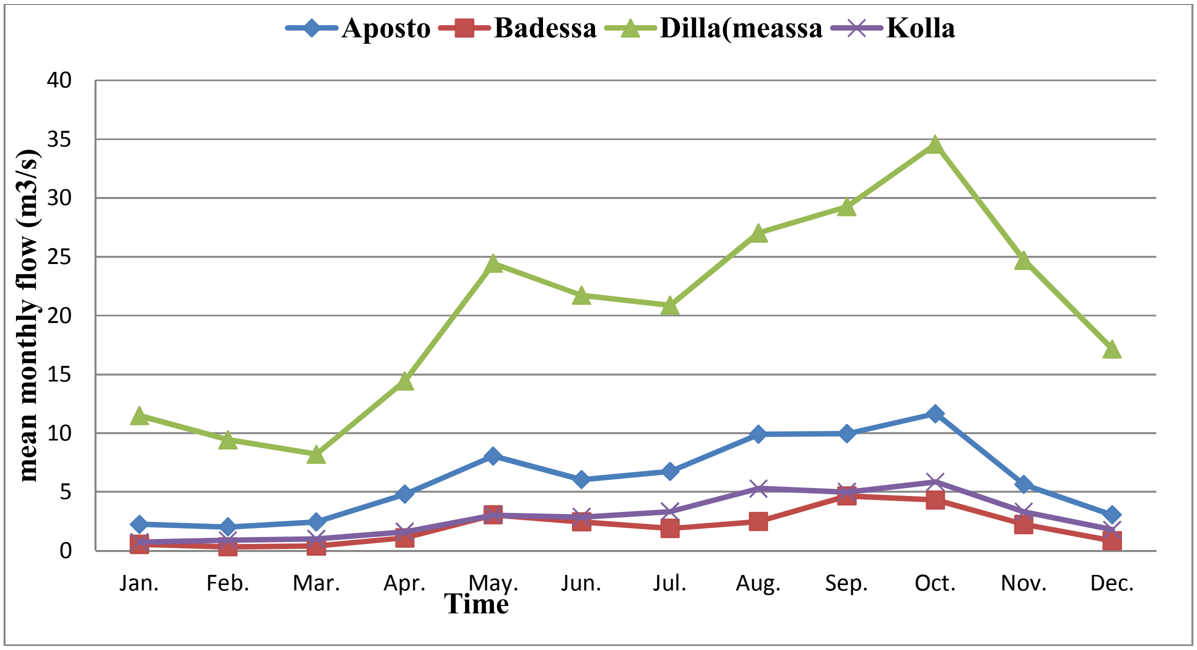
Appendix II: Average monthly rain fall of Gidabo river watershed (different weather station)

Month	Aleta Wondo	Morcho	Yirgalem	Dilla
Jan	1.319	1.331	0.942	1.115
Feb	1.701	1.960	0.933	2.594
Mar	3.566	3.729	2.800	4.287
Apr	6.591	5.020	5.203	6.489
May	7.418	4.636	5.694	6.854
Jun	4.749	3.020	3.326	3.712
Jul	4.766	3.699	3.653	3.126
Aug	5.068	3.882	4.384	3.871
Sept	7.532	5.541	4.900	6.216
Oct	5.617	4.102	5.239	5.883
Nov	2.383	1.649	1.550	2.266
Dec	1.057	0.635	0.735	0.914

Appendix III: Average monthly climate data of Gidabo river watershed (Dilla weather station)

Months	Max. Temp(c^0)	Min. Temp(c^0)	Relative Humidity (%)	Wind Speed(km/day)	Sunshine Hour (hrs.)
Jan	29.40	10.16	49	0.50	6
Feb	29.41	10.18	41	0.63	5
Mar	30.31	12.27	46	0.64	6
Apr	27.96	13.71	51	0.52	5
May	26.70	13.69	57	0.43	4
Jun	25.90	13.63	57	0.39	4
Jul	25.12	14.05	58	0.32	3
Aug	25.61	14.16	54	0.33	3
Sep	25.78	13.50	53	0.36	3
Oct	26.54	13.16	54	0.38	4
Nov	27.68	11.49	48	0.37	4
Dec	28.20	10.02	41	0.40	5

Appendix IV: Average monthly flow of Gidabo river watershed



Appendix V: Soils parameters and legend used in SWAT model

NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrologic group (A,B,C,D)
SOL_ZMX	Maximum root depth of the soil
ANION_EXCL	Fraction of porosity from which an ions are exchanged
SOL_CRK	Crack volume potential of soil
TEXTURE	Texture of the layer
SOIL_Z	Minimum depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of soil surface to bottom of the layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Clay content
SILT	Silt content
SAND	Sand content
ROCK	Rock fragmented content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility factor(k)

Appendix V: Monthly surface flow of each sub-basin (mm)

sub basin	Area km^2	Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	212.6	7.0	9.45	9.53	10.3	8.48	3.7	7.07	8.82	15.7	10.0	4.96	4.5
2	145.7	3.4	5.53	6.47	6.04	4.98	2.8	2.77	4.91	5.24	8.57	1.07	0.5
3	569.4	107	11.5	13.9	10.4	7.87	4.0	4.55	7.48	7.95	12.9	1.72	0.8
4	197.4	6.2	5.82	7.49	6.23	7.82	3.4	5.81	7.29	12.6	9.79	2.50	0.5
5	204.9	6.1	8.37	11.9	9.60	11.9	4.9	7.12	7.84	12.2	9.88	2.41	0.4
6	106.2	1.2	1.89	5.53	6.04	6.38	2.7	5.24	6.86	12.3	9.55	2.47	2.5
7	187.4	9.9	31.7	39.7	39.8	45.7	25.	22.9	27.3	39.1	42.3	23.2	12.
8	52.46	1.3	4.52	2.62	3.17	3.63	1.2	1.62	2.90	5.04	6.40	2.33	0.3
9	110.8	1.0	3.76	5.69	4.49	5.67	2.4	4.60	5.89	10.5	8.20	2.10	0.4
10	121.3	3.8	2.62	5.95	3.51	4.51	1.8	3.66	4.72	8.46	6.56	1.69	0.3
11	7.95	0.9	1.63	0.98	0.93	1.06	0.3	0.44	0.63	0.88	1.85	8.04	7.1
12	9.74	0.9	7.23	4.95	4.98	5.71	1.8	2.30	3.17	4.67	8.56	3.68	0.5
13	26.66	0.8	0.96	0.99	0.02	0.02	0.0	0.01	0.02	0.01	0.17	0.28	0.0
14	121.9	2.0	4.97	8.77	19.3	19.4	8.2	17.7	11.6	19.7	16.5	8.43	6.9
15	18.58	0.9	2.93	1.91	2.73	2.67	0.8	0.97	1.34	1.93	3.52	1.56	0.2
16	62.42	0.9	0.54	1.90	0.04	0.04	0.0	0.03	0.04	0.02	0.35	0.59	0.0
17	88.00	1.5	1.04	1.96	1.95	1.85	0.5	0.52	0.71	1.00	1.51	0.46	0.0
18	129.9	2.5	2.28	4.88	5.39	4.00	1.1	1.10	1.61	2.54	3.60	1.26	0.1
19	87.57	0.7	1.00	1.88	0.98	0.00	0.0	0.00	0.00	0.00	0.01	0.05	0.0
20	10.82	1.9	2.96	0.93	0.03	0.03	0.0	0.02	0.02	0.01	0.23	0.39	0.0
21	96.26	0.8	1.98	2.72	1.69	2.21	0.6	0.62	0.84	1.19	1.89	0.71	0.0
22	13.03	5.2	25.9	35.9	39.6	42.4	18.	21.1	22.8	33.7	36.8	18.9	9.6
23	95.42	1.1	2.68	3.87	3.64	4.78	1.2	1.31	1.80	2.56	3.91	1.22	0.1
24	110.9	3.5	0.53	4.55	2.04	0.04	0.0	0.03	0.04	0.02	0.35	0.59	0.0
25	87.32	0.8	4.15	5.99	5.64	7.40	1.8	2.02	2.76	3.96	6.03	1.84	0.2
26	215.2	7.5	10.9	9.80	7.55	5.24	1.7	7.30	4.04	7.04	8.80	7.00	0.4
27	100.1	2.1	6.54	7.87	5.80	6.31	1.6	5.73	2.37	3.38	5.14	5.57	0.1
total	**3190.6**	**85.0**	**163.4**	**208.7**	**201.9**	**210.2**	**90.7**	**126.5**	**137.8**	**211.8**	**223.5**	**105.0**	**48.2**